

Shuttle Flight Operations Manual

Vol 10 D

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Landing/Deceleration
Flight Operations Directorate
Crew Training and Procedures Division
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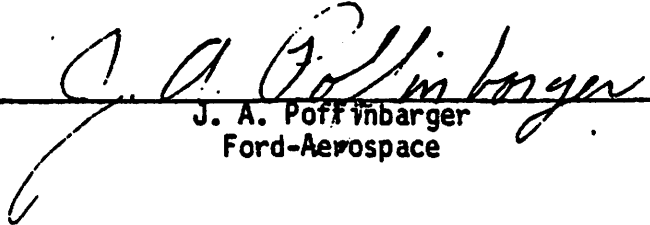
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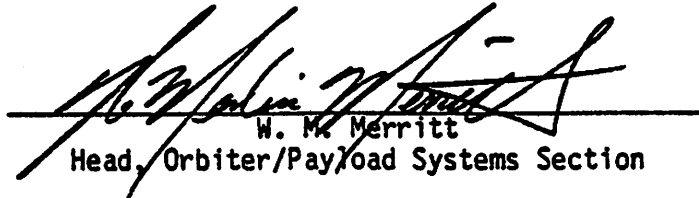
Volume 100 Landing/Deceleration

Prepared by Flight Training Branch

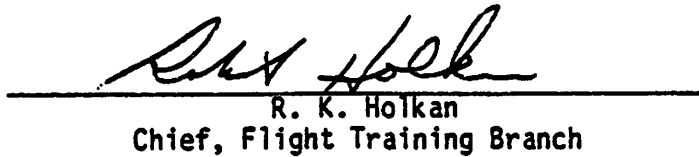


J. A. Poffinbarger
Ford-Aerospace

Approved by:



W. M. Merritt
Head, Orbiter/Payload Systems Section



R. K. Holkan
Chief, Flight Training Branch



J. W. Bilodeau
Chief, Crew Training and Procedures Division

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SECTION 1 INTRODUCTION

The purpose of the Landing/Deceleration system is to provide the capability for the Orbiter crew to perform a safe landing on its landing gears and to steer and brake the vehicle to a safe stop. The Landing/Deceleration system consists of three major subsystems: Landing Gears, Brakes/Skid Control, and Nose Wheel Steering.

- Landing Gears - The Orbiter landing gears are arranged in a tricycle gear configuration. The Nose Landing Gear (NLG) retracts forward and up into the forward fuselage. The Main Landing Gears (MLG) retract forward and up into the wings. Each gear is held in the retracted position by an uplock hook. When the crew requests gear deployment, Orbiter hydraulics will release the uplock hooks and the gears will freefall to the down and locked position. If hydraulics fail to release the gears then a backup pyrotechnic system will perform the function, 1 sec after gear deployment is requested.
- Brakes/Skid Control - Each main landing gear wheel contains electro-hydraulic disc brakes with a skid control system. The brakes are controlled electrically by signals from the crew's rudder/brake pedals. The signals control modulating servo valves on each main wheel which allow hydraulic pressure to perform braking. The brake system also contains a skid control system. The skid control system uses wheel velocity data and controls braking as required to provide optimum braking without tire skidding, wheel locking, or tire damage. The Brake/Skid Control system is a redundant system which utilizes all three hydraulic systems and is provided electrical power by all three main DC buses.
- Nose Wheel Steering - The Orbiter has Nose Wheel Steering (NWS) capability. The nose landing gear strut contains a hydraulic steering actuator which is electrically controlled by signals from the crew's rudder pedals. When the NWS System is activated the crew can perform NWS by using the rudder pedals. Signals from the rudder pedals will also control the rudder which also performs vehicle steering. The Orbiter crew can also steer the vehicle by differential braking of the main wheel brakes.

All major Landing/Deceleration system's subsystems, and their control and operations, are described in detail in Section 3.

SECTION 2
SYSTEMS INTERFACES

The Landing/Deceleration system interfaces with the Electrical Power System (EPS) and the hydraulic system. The EPS provides power to the landing/deceleration system circuits, and the hydraulic system provides hydraulic power to the landing gear uplock release mechanisms, the nose gear steering actuator, and the main gear brakes. These interfaces are depicted below in Figure 2-1.

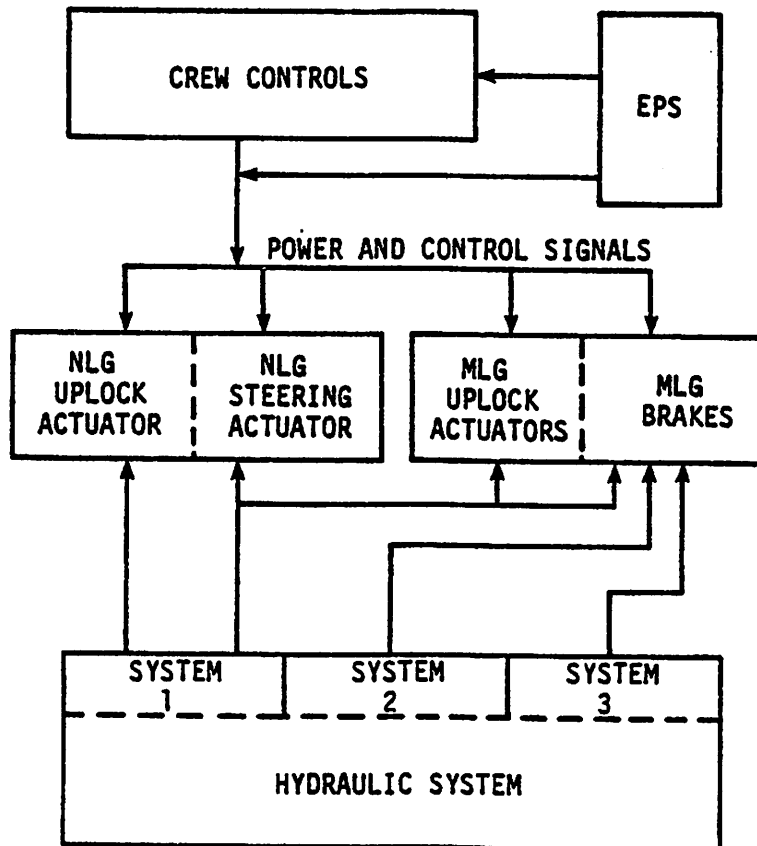


Figure 2-1.- Landing/deceleration interfaces.

SECTION 3 SYSTEM DESCRIPTION

The Landing/Deceleration system consists of three major subsystems: Landing Gears, Brakes/Skid Control, and Nose Wheel Steering. These subsystems are described in detail in subsequent paragraphs.

3.1 LANDING GEARS SUBSYSTEM

3.1.1 Nose Landing Gear

Figures 3-1 and 3-2 depict the NLG. The major NLG components are described below:

- Tires - The NLG tubeless tires are rated for a maximum of 225 knots with maximum Orbiter load. The NLG tires are inflated to 300 psi and will withstand a burst pressure of not less than 3.2 times the normal tire inflating pressure. The maximum tested load per NLG tire to prevent tire damage is 45,000 lb. The tires are rated for five normal landings. However, each tire will be inspected after each flight and will be replaced, if necessary.
- Shock Strut - The NLG shock strut along with the MLG shock struts are the primary source of shock attenuation during landing. The shock strut is a conventional pneudraulic (air/oil) shock absorber and is serviced by ground crews prior to each flight. The NLG shock strut has a 22-in stroke. The maximum derotation rate for the NLG to prevent gear and tire damage is approximately 9.4⁰ per second (11 ft/s).
- Steering/Damping Actuator - The NLG contains a steering/damping actuator which provides for Nose Wheel Steering (NWS). The steering actuator is electrically controlled and is powered by Hydraulic System 1. When NWS is not activated, the actuator provides wheel damping to prevent wheel shimmy and allows the nose wheels to free castor thru $\pm 10^0$ of rotation.
- Extend/Retract Hydraulic Strut Actuator - The extend/retract actuator is powered by Hydraulic System 1 and provides the capability for ground retraction of the gear. Gear retraction is only a ground function; the gears cannot be retracted during flight. The strut actuator contains an oil snubber which will snub the gear during freefall to prevent any damage to the gear and linkages. During gear deployment, the strut actuator will also assist in gear extension. However, if Hydraulic System 1 is down, the gear will extend without assistance from the strut actuator. Without assistance from the strut actuator, the gear will require approximately one additional second to freefall to the down and lock position.
- Door Extend/Retract Mechanism - The door extend/retract mechanism is connected to the gear linkages. As the gear freefalls, the door extend/retract mechanism will open the door. Conversely, when the gear is retracted, the mechanism will close the door.

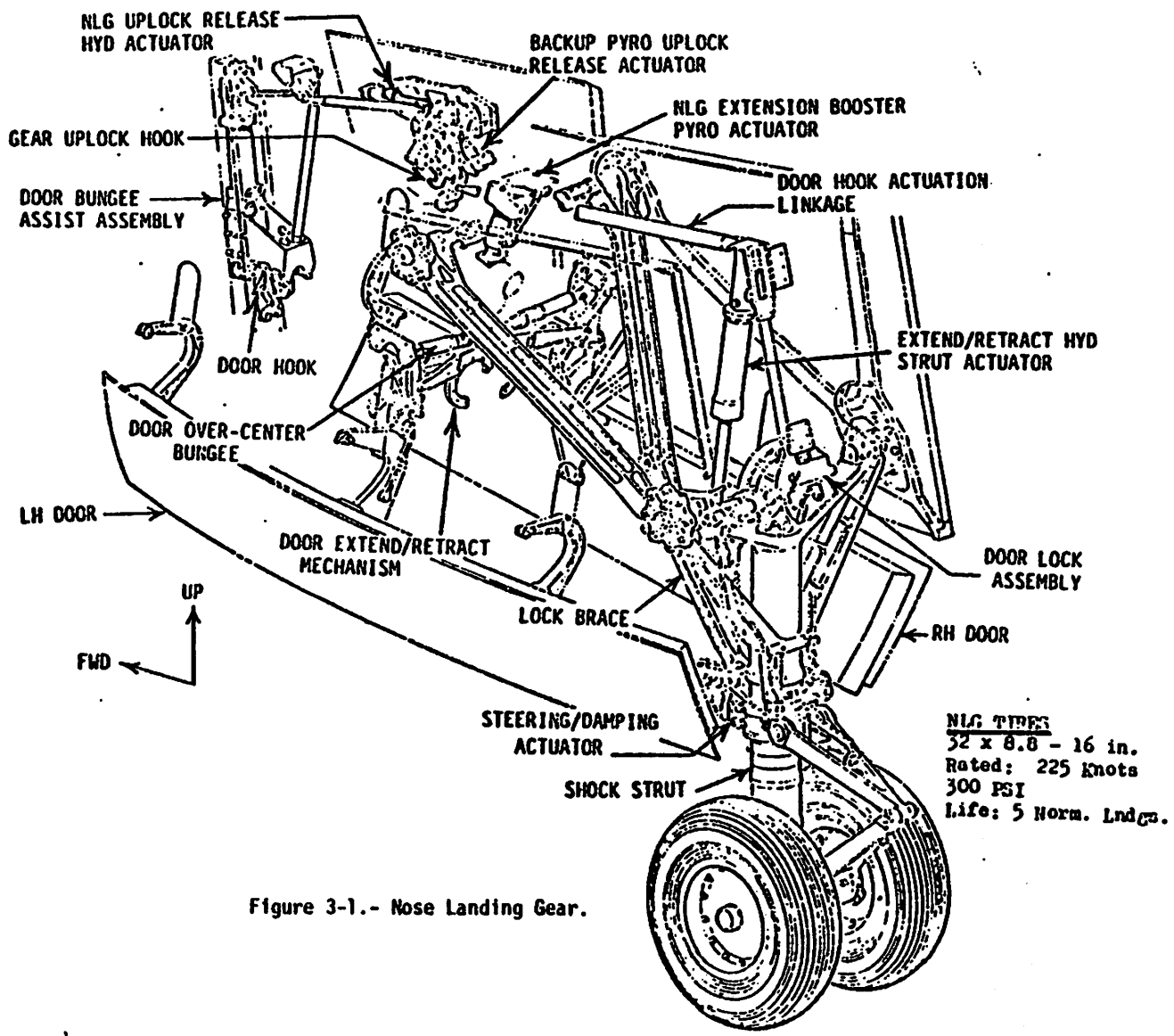
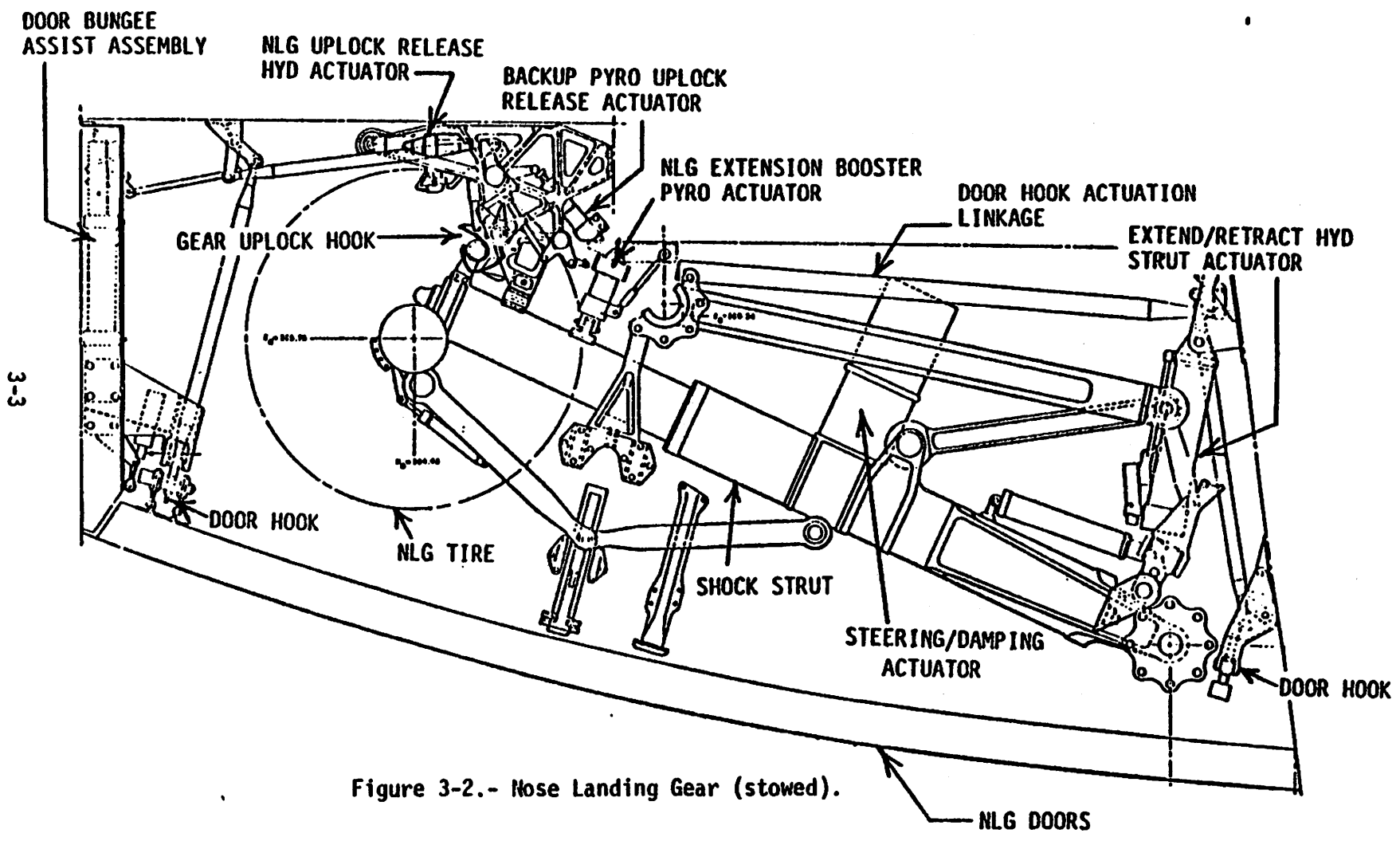


Figure 3-1.- Nose Landing Gear.

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- Door Over-Center Bungee - The door over-center bungee holds the door open when the door passes the over-center position.
- Gear Uplock Hook - The NLG is held in the stowed (retracted) position by an uplock hook which is held in position by an over-center mechanism.
- Door Hooks - The NLG has two door hooks which hold the doors closed when the gear is up.
- Door Hook Actuation Linkage - The door hook actuation linkage is connected to the uplock hook mechanism. The door hooks are released when the uplock hook is released.
- NLG Uplock Release Hydraulic Actuator - The NLG is released by an uplock release hydraulic actuator which is powered by Hydraulic System 1. When gear deployment is requested, the uplock release hydraulic actuator will release the gear uplock hook which will then release the door hooks and allow the gears to freefall.
- Backup Pyro Uplock Release Actuator - The uplock release hydraulic actuator is backed up by a backup pyro uplock release actuator. When the landing gears are commanded to be deployed, the uplock release hydraulic actuator should release the gear uplock hook. In the event the uplock actuator does not release the uplock hook within 1 sec, the backup pyro uplock release actuator will release the uplock hook. The pyro actuator is fired by dual Pyrotechnic Initiator Controllers (PIC's) and NASA Standard Initiators (NSI's). The PIC's (PIC 1 and PIC 2) are powered by redundant main buses. The circuit logic which provide power to arm and fire the PIC's are discussed in paragraph 3.1.3.1 of this manual.
- NLG Extension Booster Pyro Actuator - The NLG extension booster pyro actuator will aid in NLG extension by applying a force to the strut. The purpose of this actuator is to aid in gear extension in case high air loads are on the outside of the doors during a high angle of attack. The booster actuator is fired by dual PIC's/NSI's. When uplock hook release is sensed, the booster actuator PIC's (PIC 1 and PIC 2) will fire causing the actuator to apply force to the NLG strut. The booster actuator PIC's will fire approximately 2 sec after gear extension is requested. The circuit logic which arms and fires the PIC's is discussed in paragraph 3.1.3.2.
- Door Bungee Assist Assembly - The door bungee assist mechanism will assist in the initial door opening. This mechanism will assure door opening in case the wheel well pressure is less than the outside pressure. The mechanism contains a spring bungee which is cocked by ground personnel prior to retracting the gears. When the gears are commanded to be deployed, the door bungee assist spring mechanism will release and apply a force to the inside of the doors as soon as the door hooks are released. The spring will apply approximately 2000 lb of force to the doors over the first 2 in. of travel.

3.1.1.1 Nose gear and door uplock mechanism.- Each major NLG uplock release and extension component was discussed separately in the previous pages. The next paragraph is a brief summary of how the nose gear and door uplock mechanism functionally operates. The nose gear and door uplock mechanism is shown in Figure 3-3.

The NLG is held in the UP position by the uplock hook which is held in position by an over-center bungee. When gear deployment is requested, the NLG uplock release hydraulic actuator will release the uplock hook which will move the door hook actuation linkage which will release the door hooks. Once the door hooks are released, the door bungee assist assembly will aid in door opening. When the uplock hook is released, simultaneously, the door will open and the NLG will freefall to the down and locked position. If the hydraulic actuator fails to release the uplock hook, the backup pyro actuator will release the hook, 1 sec after gear deployment is requested.

3.1.2 Main Landing Gear

The MLG is depicted in Figures 3-4, 3-5, and 3-6. The MLG major components, their purposes and operation, are basically the same as the NLG. Several exceptions are as follows:

- **Tires** - The MLG tires are inflated to 260 psi. The maximum tested load per MLG tire to prevent tire damage is 100,000 lb. If the Orbiter main gears touchdown with equal weight distribution on all four tires then both tires on a strut can support a load of 200,000 lb. However, if the Orbiter touchdown with a 60/40 percent load distribution on a strut's two tires, with one tire supporting the maximum load of 100,000 lb, then the other tire can support a load of only 67,000 lb. Therefore, the maximum tire load on a strut is only 167,000 lb. with a 60/40 percent tire load distribution.
- **Shock Strut** - The MLG shock struts have a 16-in. stroke. The maximum allowable main gear sink rate for a 188,000 lb Orbiter is 9.6 ft/s and 6.0 ft/s with a 226,000 lb Orbiter. With a 20-knot crosswind, the maximum allowable main gear sink rate for a 188,000 lb Orbiter is 6.0 ft/s and approximately 5.0 ft/s with a 226,000 lb Orbiter.
- **Door Bungee Assist Mechanism** - The MLG door bungee assist mechanism will apply approximately 5000 lb of force to the inside of the doors over the first 2 in. of travel.
- **Door Hooks** - Each MLG has four door hooks.

The main landing gears do not have extension booster pyro actuators.

**NOSE GEAR & DOOR UPLOCK
MECHANISM**

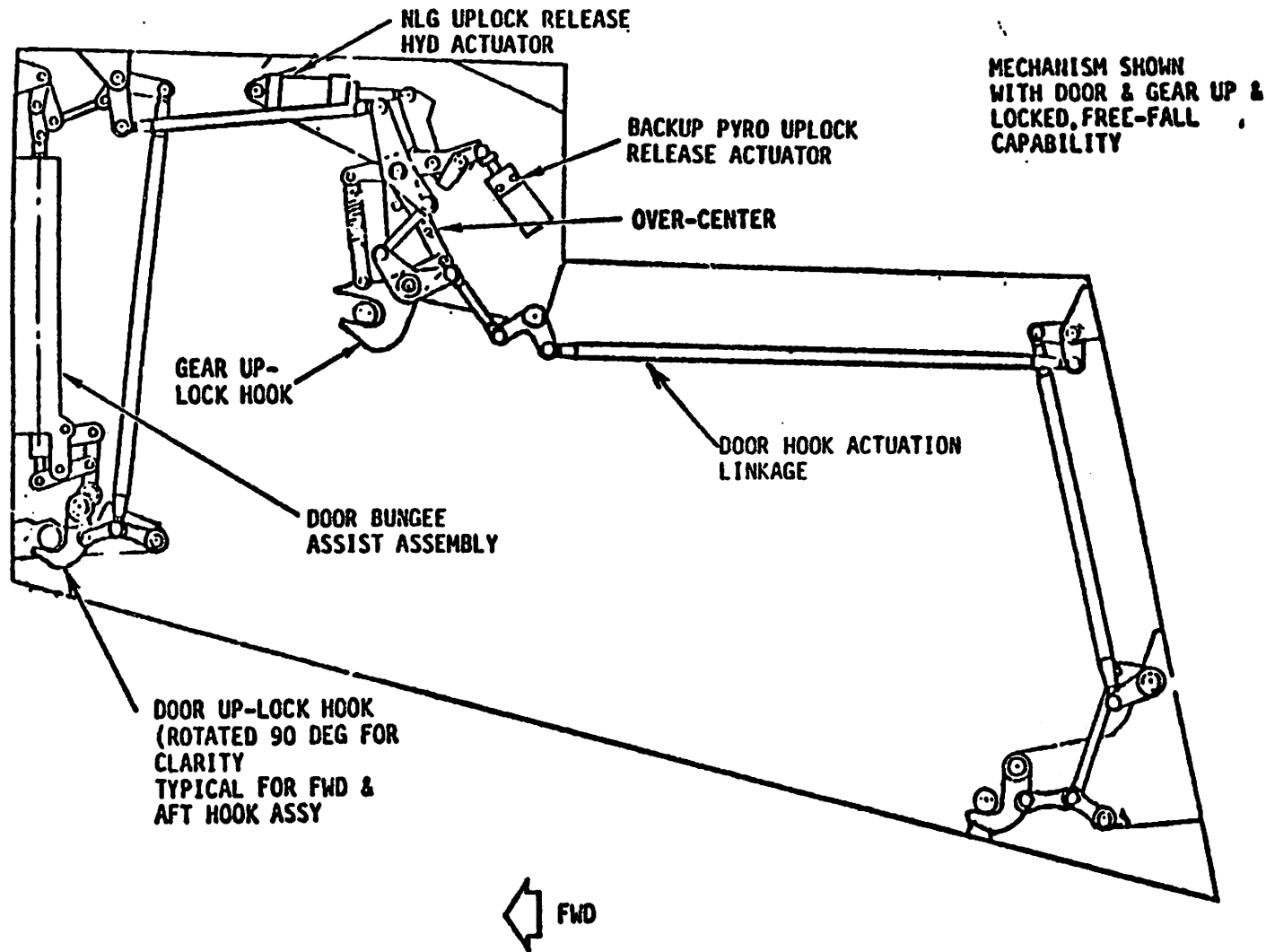


Figure 3-3.- Nose gear and door uplock mechanism.

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3-7

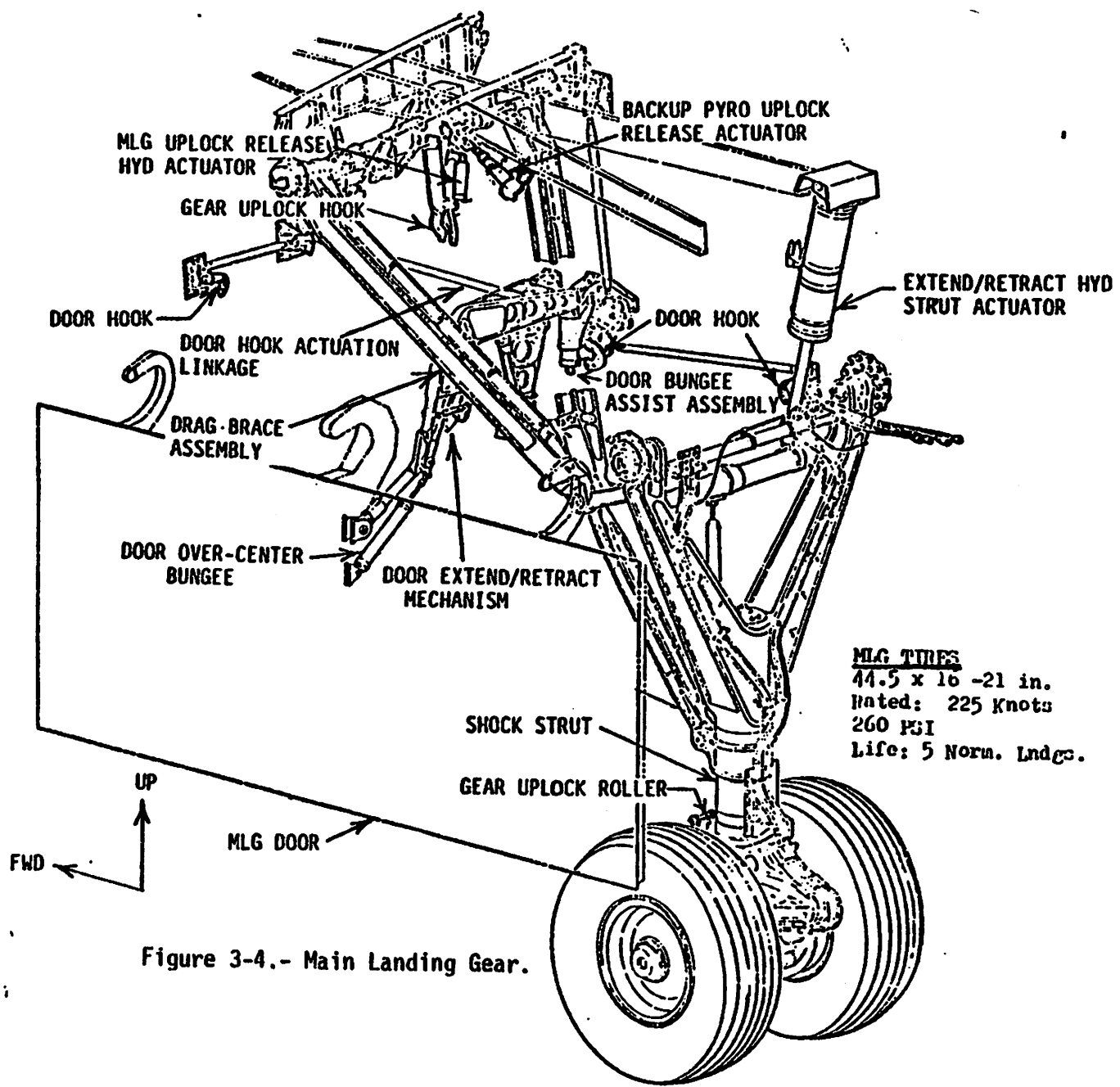


Figure 3-4.- Main Landing Gear.

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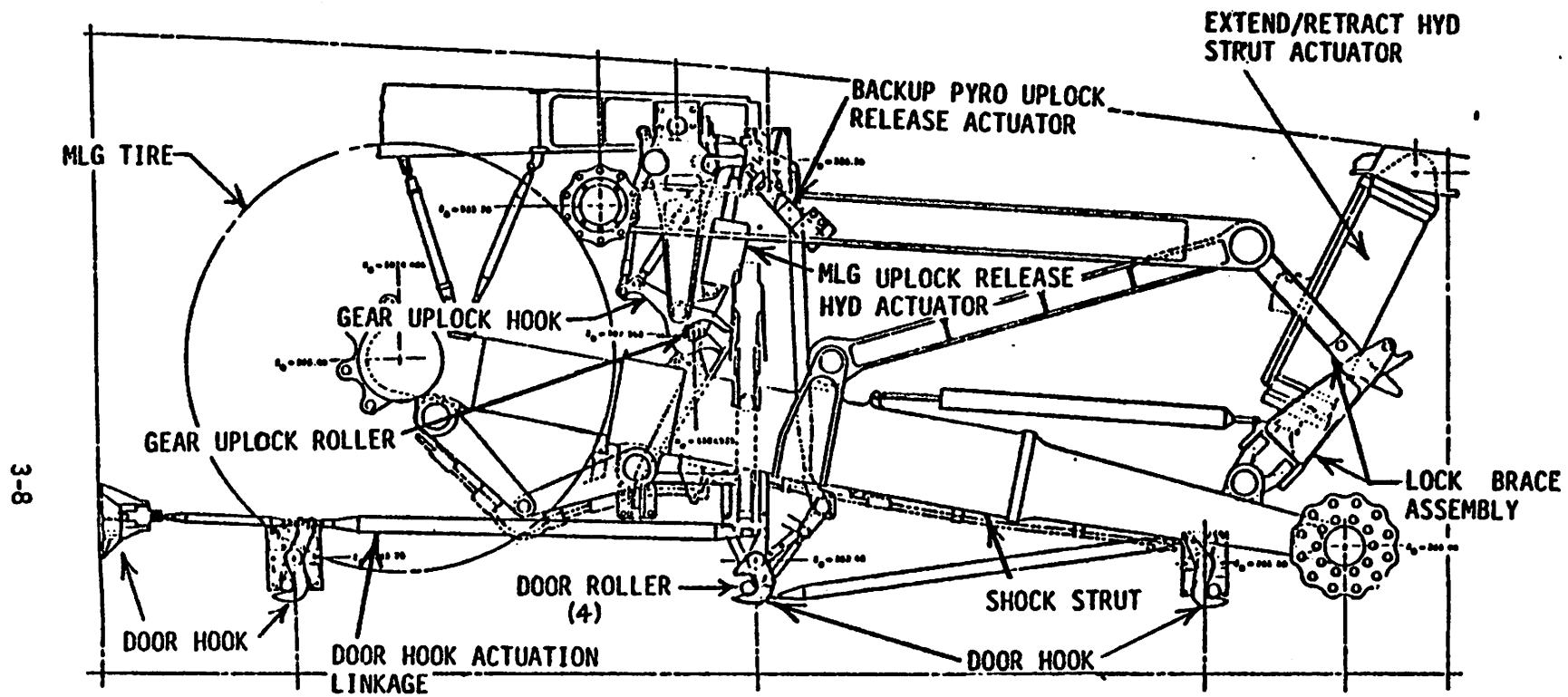


Figure 3-5.- Main Landing Gear (stowed).

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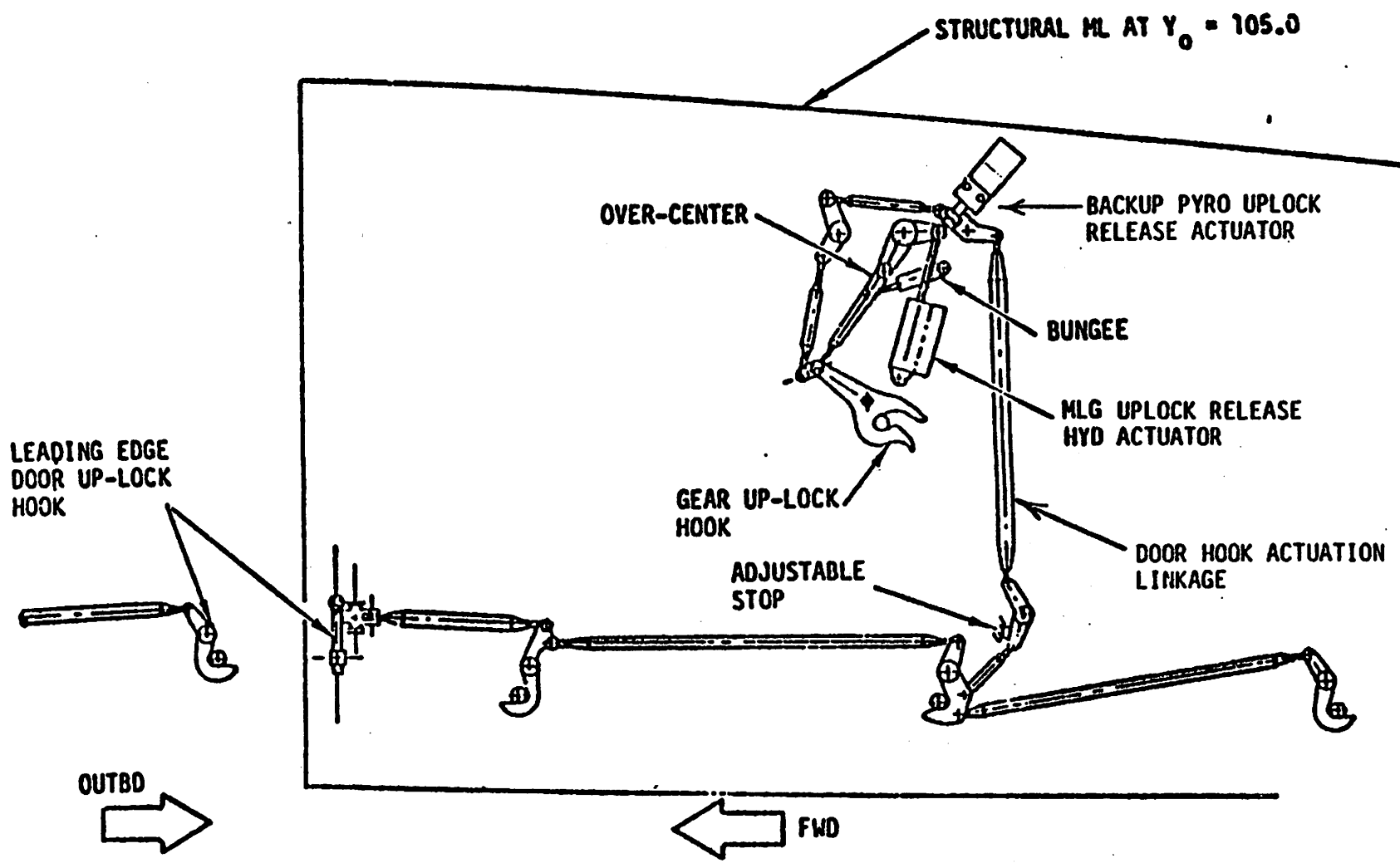


Figure 3-6.- Main gear and door uplock mechanism.

3.1.3 Landing Gear Proximity Sensors and Indicators

The landing gear proximity sensors are distributed throughout the NLG and MLG areas and are separated into two sensor packages as shown in Figure 3-7. These sensors output signals which drive the landing gear position indicators. The sensors also output signals (see footnotes on Figure 3-7) to the following circuits:

- 1 TO BACKUP PYRO UPLOCK RELEASE ACTUATOR PIC 1 CIRCUITS
- 2 TO BACKUP PYRO UPLOCK RELEASE ACTUATOR PIC 2 CIRCUITS
- 3 TO NLG EXTENSION BOOSTER PYRO ACTUATOR PIC 1 CIRCUITS
- 4 TO NLG EXTENSION BOOSTER PYRO ACTUATOR PIC 2 CIRCUITS
- 5 TO BRAKES/ANTISKID CIRCUITS
- 6 TO GUIDANCE, NAVIGATION, AND CONTROL

As depicted in Figure 3-7 the proximity sensors packages are powered up by closing the LG SNSR 1 and LG SNSR 2 circuit breakers on Panel L4. When a sensor is sensing its appropriate function it will output a signal to a circuit driver which will allow main bus power to complete the circuit; Main Bus C provides power to Sensor Package 1 and Main Bus B provides power to Sensor Package 2. Loss of power from a circuit breaker or main bus power means loss of the appropriate sensor package.

It should be noted that each sensor package contains a gear uplock sensor for each of the landing gears. For example, Sensor Package 1 has a NLG DOOR UPLK sensor and Sensor Package 2 has a NLG UPLK sensor. Both of these sensors will output signals when the NLG is up. As shown on the drawing, these two signals are both required (i.e., ANDED together) to drive the NLG position indicator UP flag. The main gear uplock sensors are also ANDED together. If any of the uplock sensor signals were lost, the appropriate UP flag would go to barberpole.

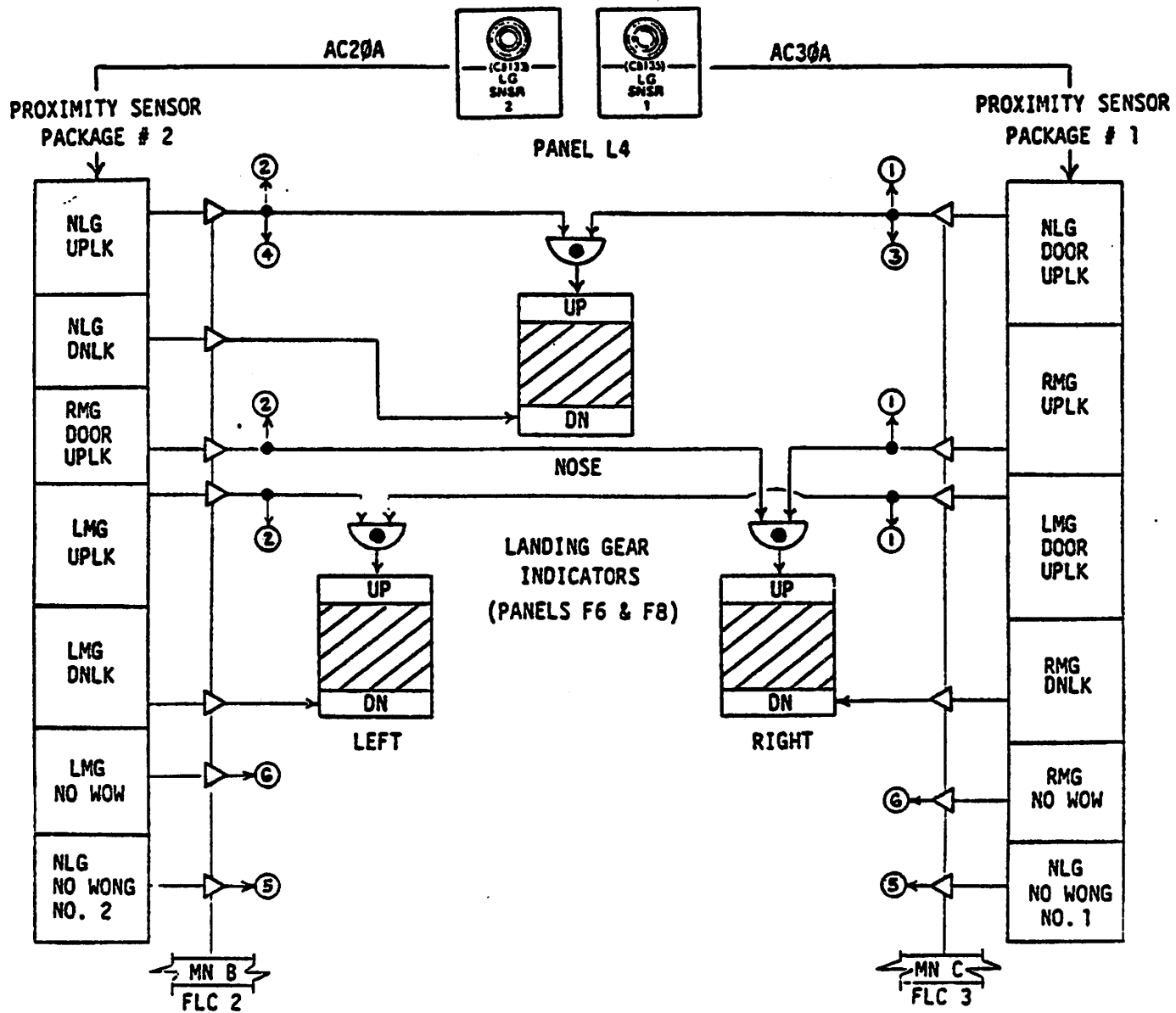


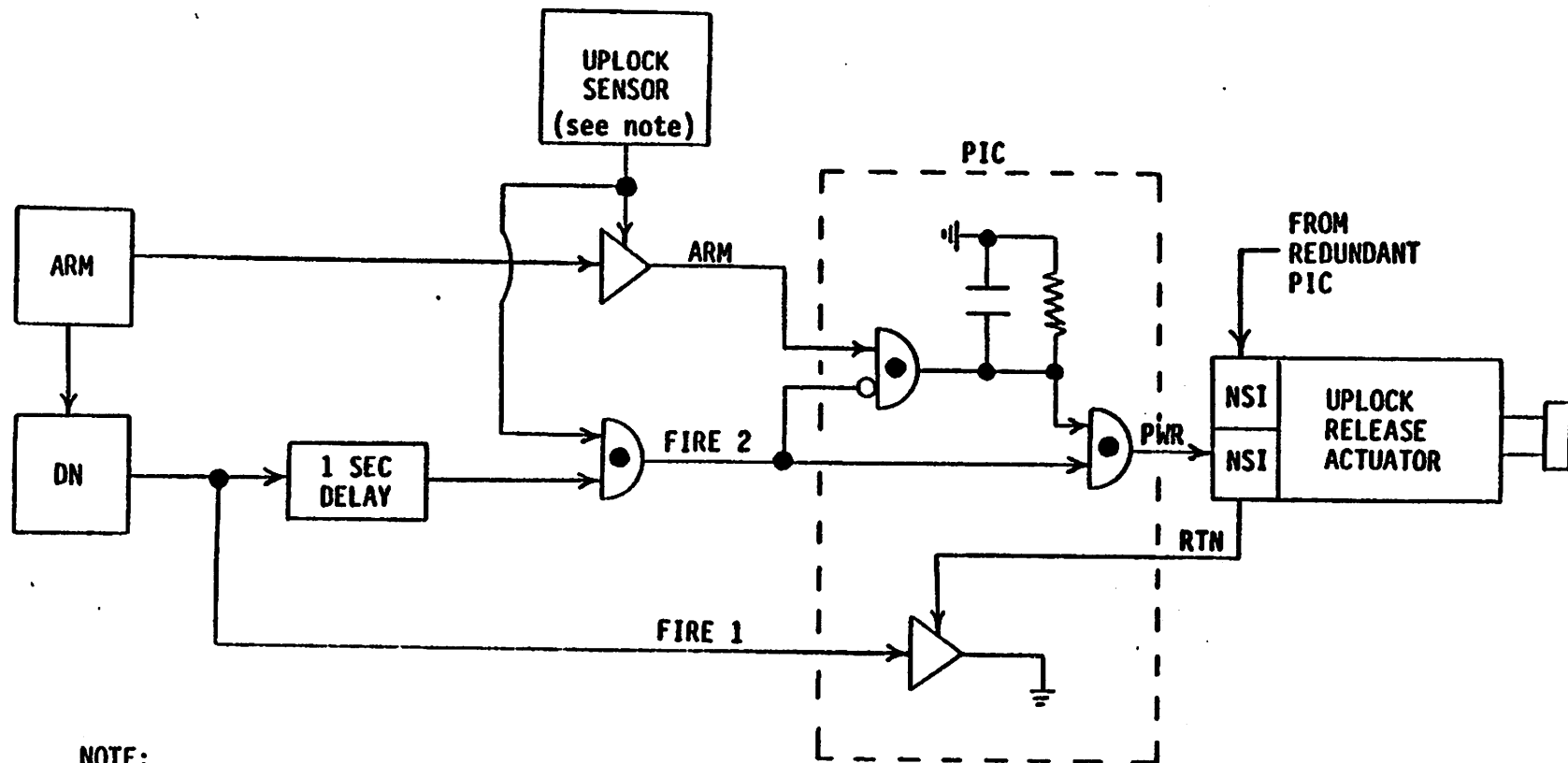
Figure 3-7.- Landing gear sensors and indicators.

3.1.3.1 NLG and MLG uplock release pyro actuator circuit.- The purpose of each of the NLG and MLG backup pyro uplock release actuators is to release the gear uplock hook if the uplock release hydraulic actuator fails to do so within 1 sec after gear deployment is requested. As discussed in previous sections, each backup pyro uplock release actuator is fired by dual (redundant) PIC's. Although the dual PIC's (PIC 1 and PIC 2) simultaneously fire, only one PIC is required. Whether or not a PIC fires depends on an output signal from its associated gear uplock sensor. Figure 3-7 defines which uplock sensors are associated with which PIC circuits. The simplified circuit drawing in Figure 3-8 depicts how each uplock sensor governs the firing of its associated PIC and NSI. A brief description of how this circuit works is provided in the following paragraph.

After activation of the ARM PBI, main bus voltage will arm the uplock release PIC. The PIC requires approximately 40 ms to be armed. After activation of the DN PBI main bus voltage is sent to the FIRE 1 and FIRE 2 paths. The FIRE 1 path completes the ground to the NSI which is to be fired. The FIRE 2 path will fire the PIC in 1 sec if the uplock sensor continues to output a signal to the FIRE 2 "AND" gate. If uplock release is accomplished by the hydraulic actuator within 1 sec after gear deployment is requested, the uplock sensor signal will cease and the FIRE 2 "AND" gate will not allow the PIC to fire the NSI.

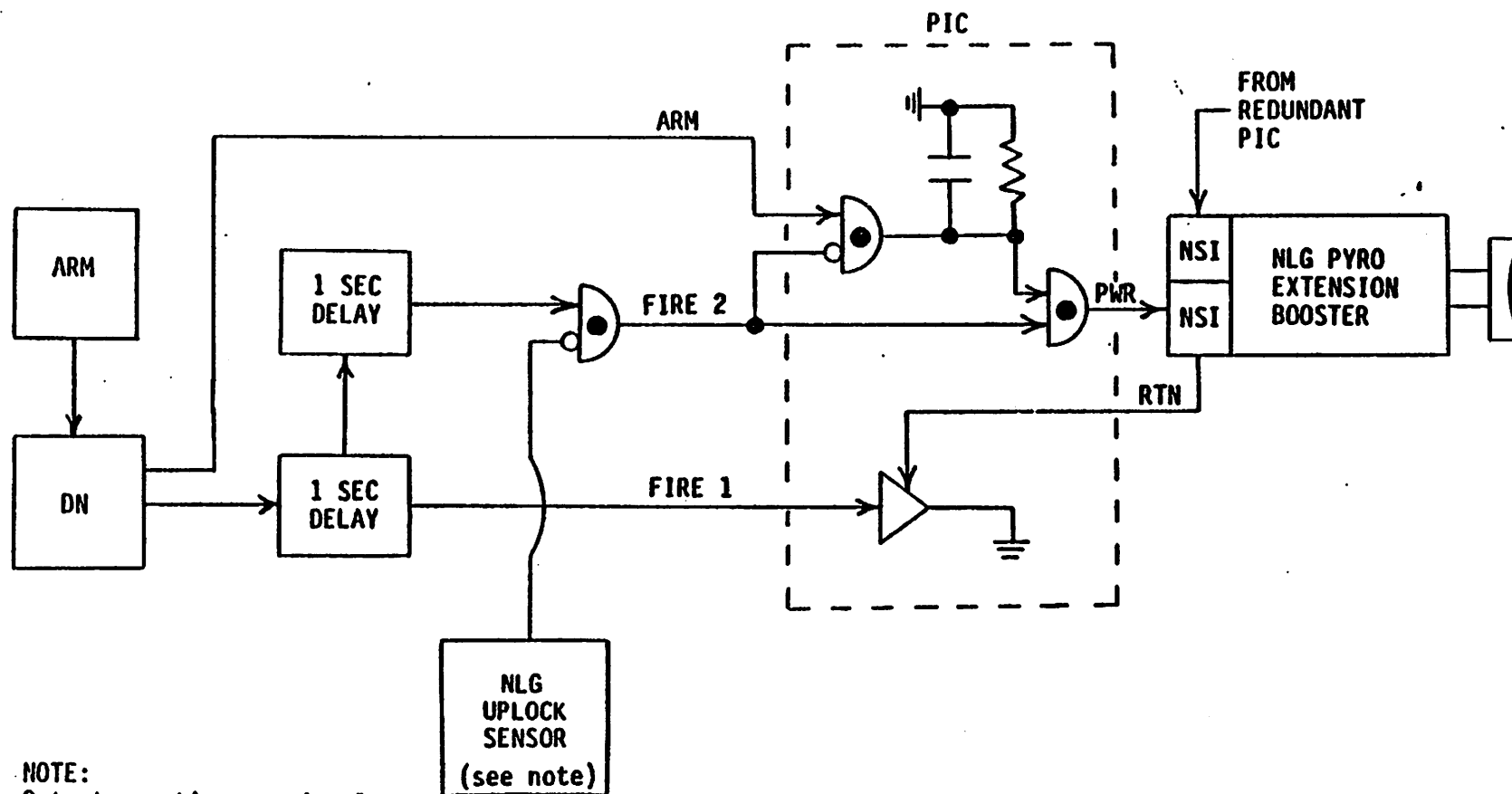
3.1.3.2 Nose landing gear extension booster pyro circuit.- The purpose of the nose landing gear extension booster is to aid in NLG extension by applying a force to the strut approximately 2 sec after gear extension is requested if uplock hook release is sensed. If uplock hook release is not sensed, the extension booster pyro actuator will not fire. As discussed in previous sections, the pyro actuator is fired by dual PIC's and NSI's. Whether or not a PIC fires depends on an output signal from its associated gear uplock sensor. As indicated in Figure 3-7, the NLG door uplock sensor outputs signals to the extension booster PIC 1 circuit and the NLG uplock sensor outputs signals to the extension booster PIC 2 circuit. Figure 3-9 depicts how these uplock sensors govern the firing of their associated PIC's and NSI's. A brief description of how this circuit works is provided in the following paragraph.

After activation of the ARM and DN PBI's, main bus voltage will be sent to the ARM, FIRE 1, and FIRE 2 paths. The ARM path will arm the PIC in approximately 40 ms. After a 1 sec delay the FIRE 1 path will complete the ground to the NSI which is to be fired. After an additional sec delay, the FIRE 2 path will allow the PIC to fire the NSI if the NLG uplock sensor signal is lost. If the uplock sensor continues to output a signal then the FIRE 2 "AND" gate will not allow the PIC to fire. The NLG extension booster will always fire approximately 2 sec after gear deployment is requested if uplock release is sensed.



NOTE:
Outputs continuous
signal while landing
gear is up and locked.

Figure 3-8.- NLG and MLG uplock release pyro actuator circuit (simplified).



NOTE:
Outputs continuous signal
while NLG is up and locked.

Figure 3-9.- Nose landing gear extension booster pyro circuit (simplified).

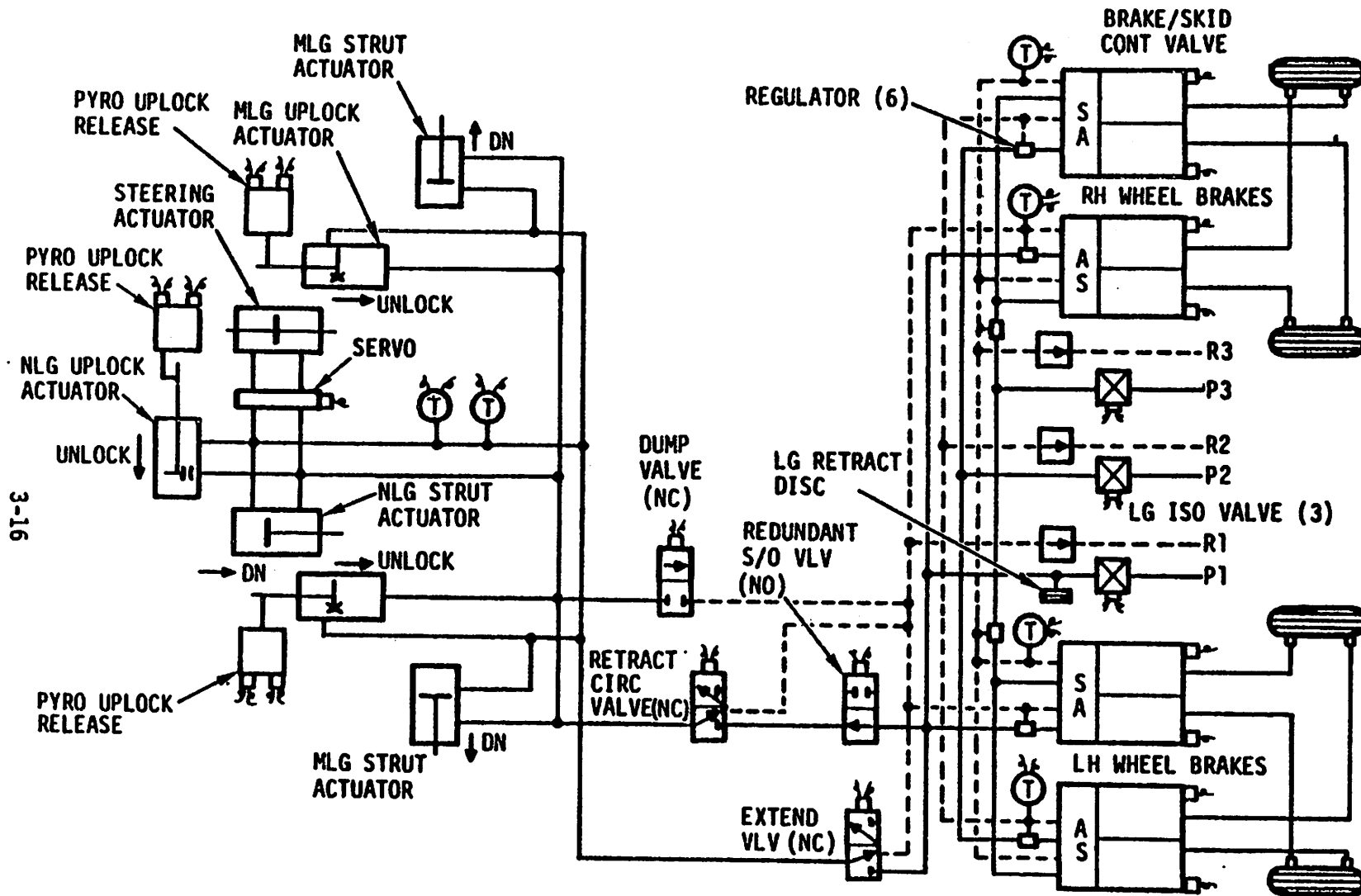
3.1.4 Landing Gear Hydraulics

Figure 3-10 depicts the landing gear hydraulic distribution and landing gear valves. A brief description of hydraulics is required to understand what happens when gear deployment is requested, i.e., the ARM and DN PBI's are activated.

The NLG and MLG are supplied hydraulic pressure from only Hydraulic System 1. The main gear brakes receive hydraulic pressure from all three hydraulic systems. (The brake system will be discussed in a later section.) System 1 supplies hydraulic pressure to the landing gear strut and uplock actuators for gear extension and to the NLG steering actuator which provides NWS. (NWS will be discussed in a later section.) The landing gear Hydraulic System 1 valves and their functions are as follows:

- Isolation Valve - When opened, allows hydraulic pressure to the landing gear areas when the hydraulic systems are powered up.
- Retract/Circulation Valve - This valve must be opened for gear retraction by the ground crews and for on-orbit circulation for thermal control.
- Control/Extend Valve - This valve is opened by the ARM and DN PBI circuits and allows hydraulic pressure to the strut and uplock actuators for gear extension.
- Redundant Shutoff Valve - This valve is a backup to the retract/circulation valve. It prevents hydraulic pressure from being ported to the retract side of the strut and uplock actuators if the retract/circulation valve fails open during gear extension.
- Dump Valve - This valve allows Hydraulic System 1 fluid return, i.e., hydraulic fluid from the nose and main landing gear areas is returned into Hydraulic System 1 through this valve.

The isolation valve is a latching solenoid valve which is latched open or closed. All other valves are spring loaded valves and are normally closed except the redundant S/O valve which is normally open. These spring loaded valves remain in their normal state until powered to the opposite position. When unpowered, these valves assume their normal state. The ARM and DN deployment PBI's control all these valves for gear extension except the isolation valves which are controlled manually by the crew or the GPC's. The next section will describe these valves and their relation to the ARM and DN PBI circuits.



3-16

Figure 3-10.- Landing gear hydraulic distribution.

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3.1.5 Landing Gear Deployment

Refer to Figures 3-10 and 3-11 for the discussion of landing gear deployment in this section. Either the CDR or PLT can deploy the landing gears by activation of his guarded ARM and DN PBI's. Gear deployment is accomplished by activation of the ARM PBI and then DN PBI. When the DN PBI is activated, the landing gears will extend and lock down in approximately 6-8 sec with a maximum of 10 sec. After the DN PBI is activated, the landing gear indicators will go barberpole. When the gears are down and locked, the indicators will indicate DN. The functions performed by activation of the deployment PBI's are as follows:

ARM PBI ACTIVATION - Activation of the ARM PBI will set six latching relays which will cause the following functions to be performed:

- Illuminate both ARM PBI's.
- Close (deenergize) the retract/circulation valve.
- Close (energize) the redundant shutoff valve.
- ARM the NLG and MLG uplock release PIC's.
- Provide Main Bus A, B, and C power to the DN PBI circuits.

DN PBI ACTIVATION - Activation of the DN PBI will set six latching relays which will cause the following functions to be performed.

- Illuminate both DN PBI's.
- Provide main bus power to the landing gear PIC circuits.
- Open (energize) the landing gear control extend valve to allow hydraulic pressure to extend the landing gears.
- Open (energize) the dump return valve to allow hydraulic fluid to return into Hydraulic System 1.

The maximum Orbiter velocity for landing gear deployment to prevent gear damage is 300 knots.

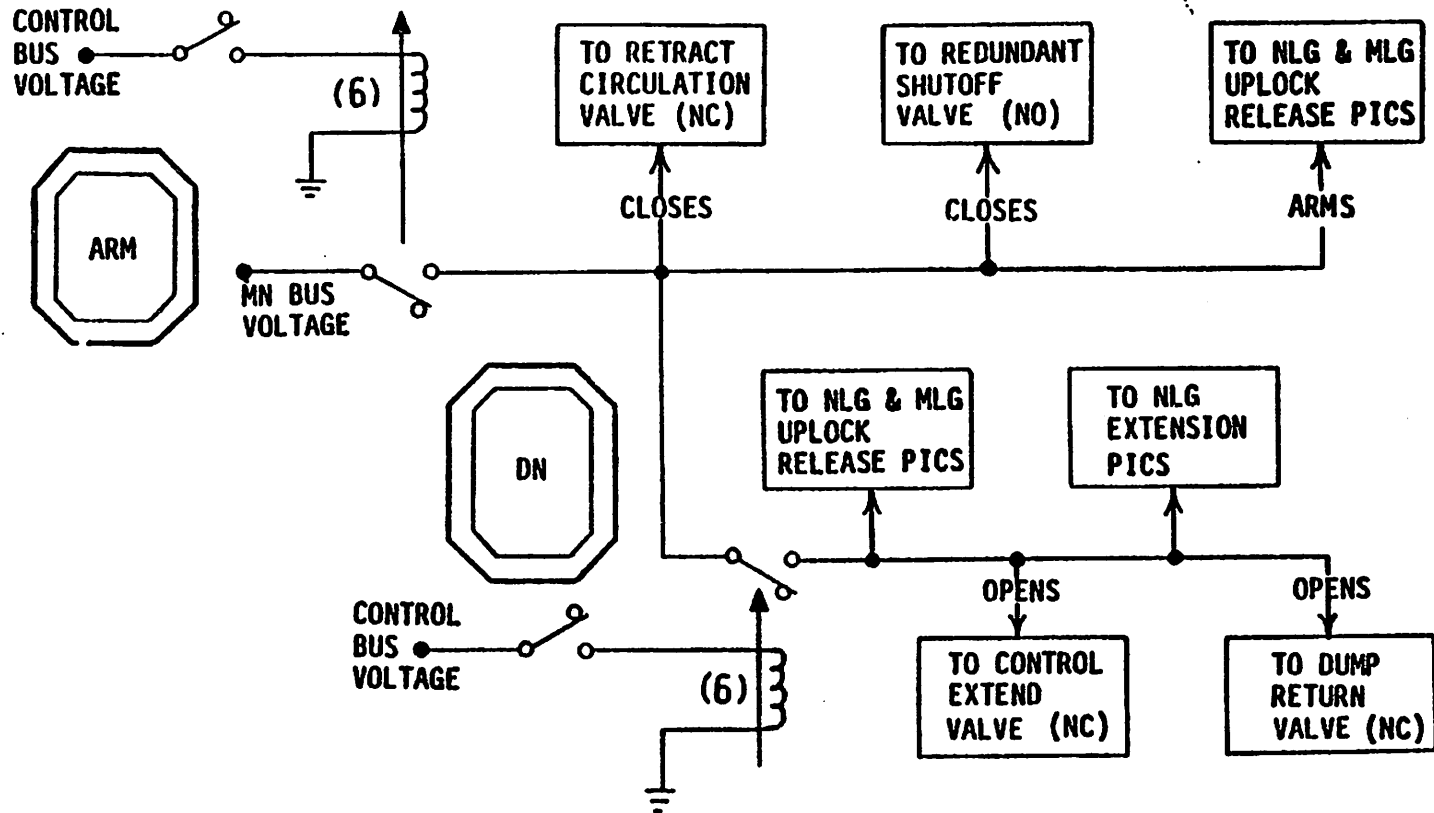


Figure 3-11.- ARM/DN circuit (simplified).

3.1.6 Landing Gear Deployment Circuit Power

The power sources for the landing gear ARM and DN PBI circuits are shown below. Basically, then the ARM/DN PBI's are activated, control buses will set (energize) the latching relays. The latching relays will then allow main buses to illuminate the ARM and DN lights and to supply power to the circuits as shown below.

ARM PBI		DOWN PBI	
<u>POWER SOURCE</u>	<u>SUPPLIES</u>	<u>POWER SOURCE</u>	<u>SUPPLIES</u>
CNTL BUSES	ARM RELAYS	CNTL BUSES	DN RELAYS
MN A, MN B, MN C	ARM LIGHT	MN A, MN B, MN C	DN LIGHTS
MN A, MN B	LG RETRACT CIRC VLV	MN A	LNDG DUMP VLV LNDG GR CNTL/ EXTEND VLV
MN B, MN C	REDUNDANT S/O VLV	MN B	LNDG GR PIC 2 CIRCUITS
MN B	ARMS UPLOCK RELEASE PIC 2 CIRCUITS	MN C	LNDG GR PIC 1 CIRCUITS
MN C	ARMS UPLOCK RELEASE PIC 1 CIRCUITS		
MN A, MN B, MN C	DOWN PBI CIRCUITS		

3.1.7 Landing Gear Circuit Reset

The purpose of the landing gear ARM/DN circuit reset function is to reset the landing gear circuit magnetic relays which were set by activation of the ARM and DN PBI's. Landing gear ARM/DN reset is primarily a ground function which will only be performed during landing gear deactivation. The controls used for this function are the LDG GEAR ARM/DN RESET ESS1BC circuit breaker on Panel R15 and the LG ARM/DN RESET momentary switch on Panel A12. Landing gear ARM/DN reset is performed by first closing the "LDG GEAR ARM/DN RESET" circuit breaker and then activating the LG ARM/DN RESET switch. The circuit breaker supplies ESS1BC power to the switch. When the LG ARM/DN RESET switch is activated to the reset position, the ESS1BC power will reset the magnetic relays which were set by activation of the "ARM" and "DN" PBI's. The circuit reset will cause the following events to occur:

- Extinguish the "ARM" and "DN" PBI lights.
- De-energize the landing gear PIC circuits.
- Close the landing gear control/extend valve.
- Close the landing gear dump return valve.
- Open the landing gear redundant S/O valve.

3.2 BRAKES AND SKID CONTROL SUBSYSTEM

3.2.1 Wheel Brake Assembly

The Orbiter is equipped with electro-hydraulic disc brakes. Figure 3-12 depicts the wheel brake assembly. The discs are constructed of beryllium metal and lined with carbon pads. Each of the four main wheels contains a disc brake assembly. Each assembly has nine discs: four rotors and five stators. The rotors are splined to the inside of the wheel and rotate with the wheel. The stators are splined to the outside of the axle assembly and do not rotate. When the brakes are applied, eight hydraulic actuators in the brake assembly press the discs together, thus providing braking torque. The hydraulic brake actuators are distributed evenly around the discs. Four of the actuators are manifolded into a brake chamber and are powered by a hydraulic system. The remaining four (every other one) are manifolded into another brake chamber and are powered by a different hydraulic system.

The brake system is organized into eight separate discrete brake/skid control circuits. Each circuit individually controls the braking performance of one main wheel brake chamber.

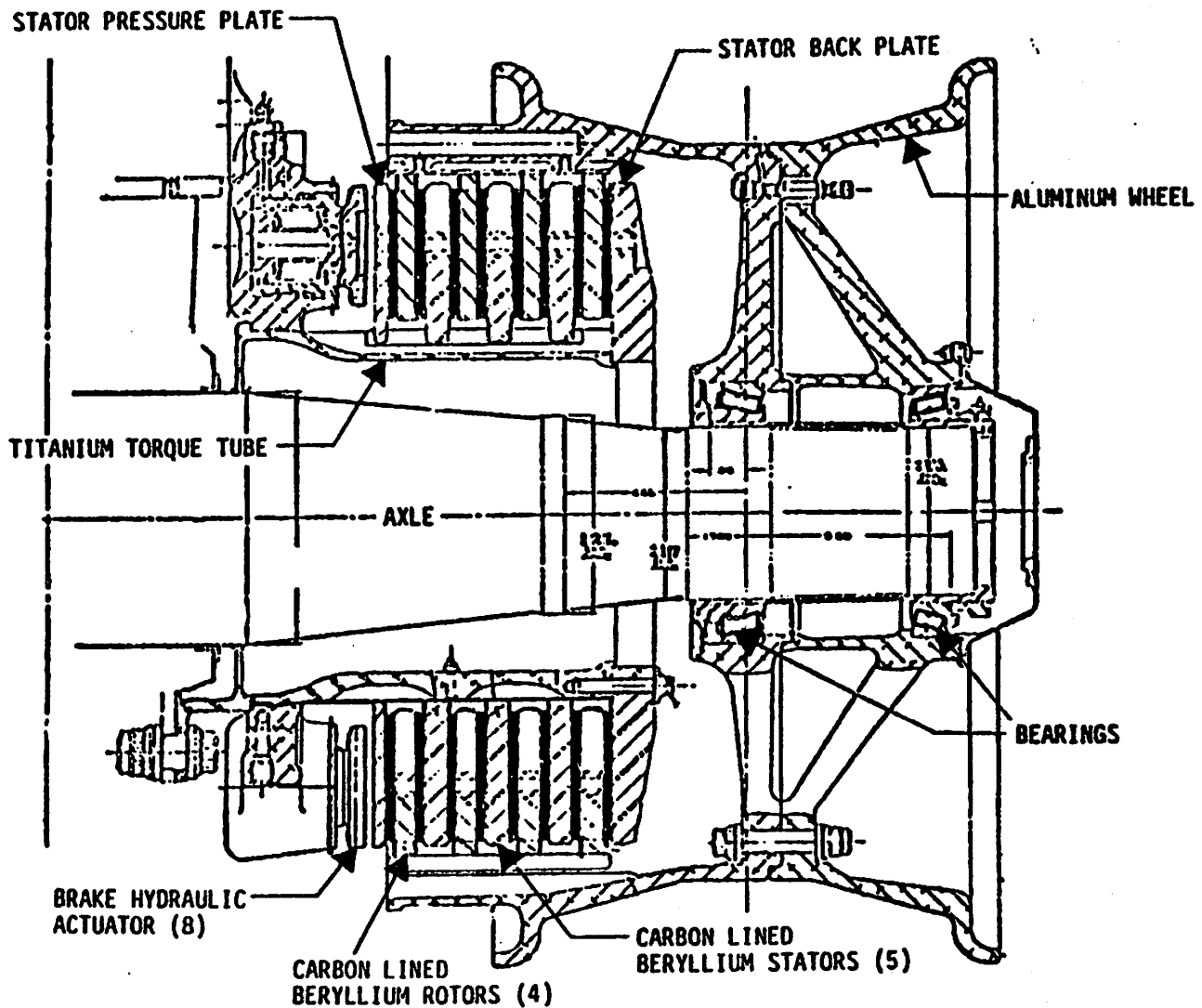


Figure 3-12.- Wheel brake assembly.

3.2.2 Rudder/Brake Pedal Assembly

The CDR and PLT both have rudder/brake pedal assemblies. A rudder/brake pedal assembly is shown in Figure 3-13. Orbiter braking is initiated by applying toe pressure on the pedals. Each rudder/brake pedal assembly contains two brake pedal transducer units. Each unit has four Linear Variable Differential Transducers (LVDT) which output 0-5 VDC brake signals to brake/skid control boxes A and B. The left transducer unit will output four separate braking signals through the brake/skid control boxes for braking control of the two left wheels. The right transducer unit will output four separate braking signals for braking control of the two right wheels.

3.2.3 Brake/Skid Control Power

The brake system is powered up by placing the brake's MN A, MN B, and MN C power switches to the ON positions. These switches provide redundant main bus power to Brake Buses CA and BC as shown in Figure 3-14. Brake Bus CA provides power to Brake/Skid Control Box A and Brake Bus BC provides power to Brake/Skid Control Box B. Each brake/skid control box contains four separate brake/skid control circuits. Each circuit controls a modulation brake/skid control solenoid valve which controls braking hydraulic pressure to a wheel. Each wheel has two brake/skid control valves. One valve is controlled by Brake/Skid Control Box A and the other valve is controlled by Brake/Skid Control Box B.

Brake/skid control power is redundant. If a main bus is lost or a power switch is not ON, the appropriate brake bus will receive full power from the redundant bus. For example, if Main Bus A is lost, Brake Bus CA will receive full power from Main Bus C. Also, since each of the two control valves on a wheel is controlled by a different brake/skid box, all three main buses provide power to the braking circuits on a wheel. All three main buses would have to be lost to have no power to any of the braking circuits of a wheel.

When the brake power switches are turned ON, the brake portion of each brake/skid control circuit is immediately powered and braking is enabled. However, the antiskid portion of each brake/skid control circuit is not powered, and antiskid is not enabled until the ANTISKID switch is turned ON. When the ANTISKID switch is OFF and BRAKE POWER switches are ON, Brake Bus BC power will illuminate the ANTISKID FAIL light.

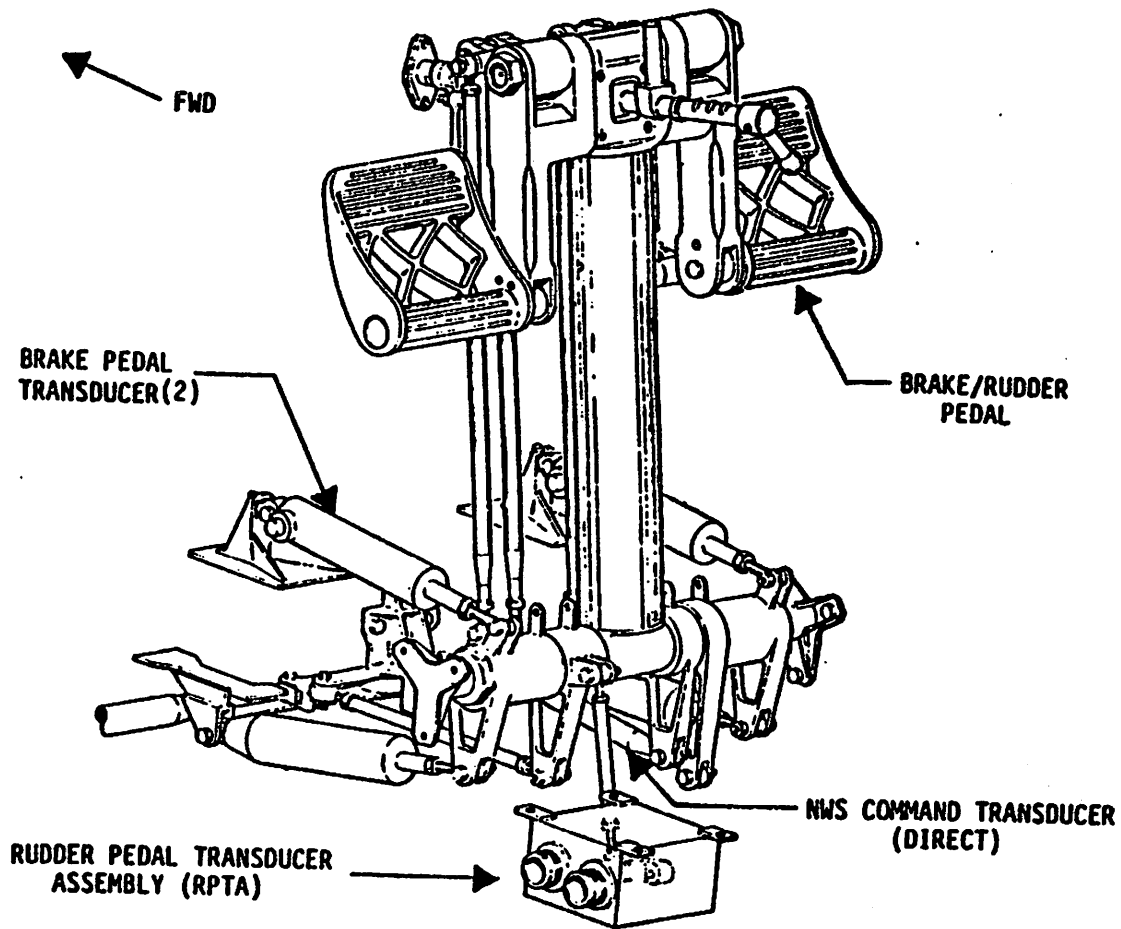


Figure 3-13.- Rudder/brake pedal assembly.

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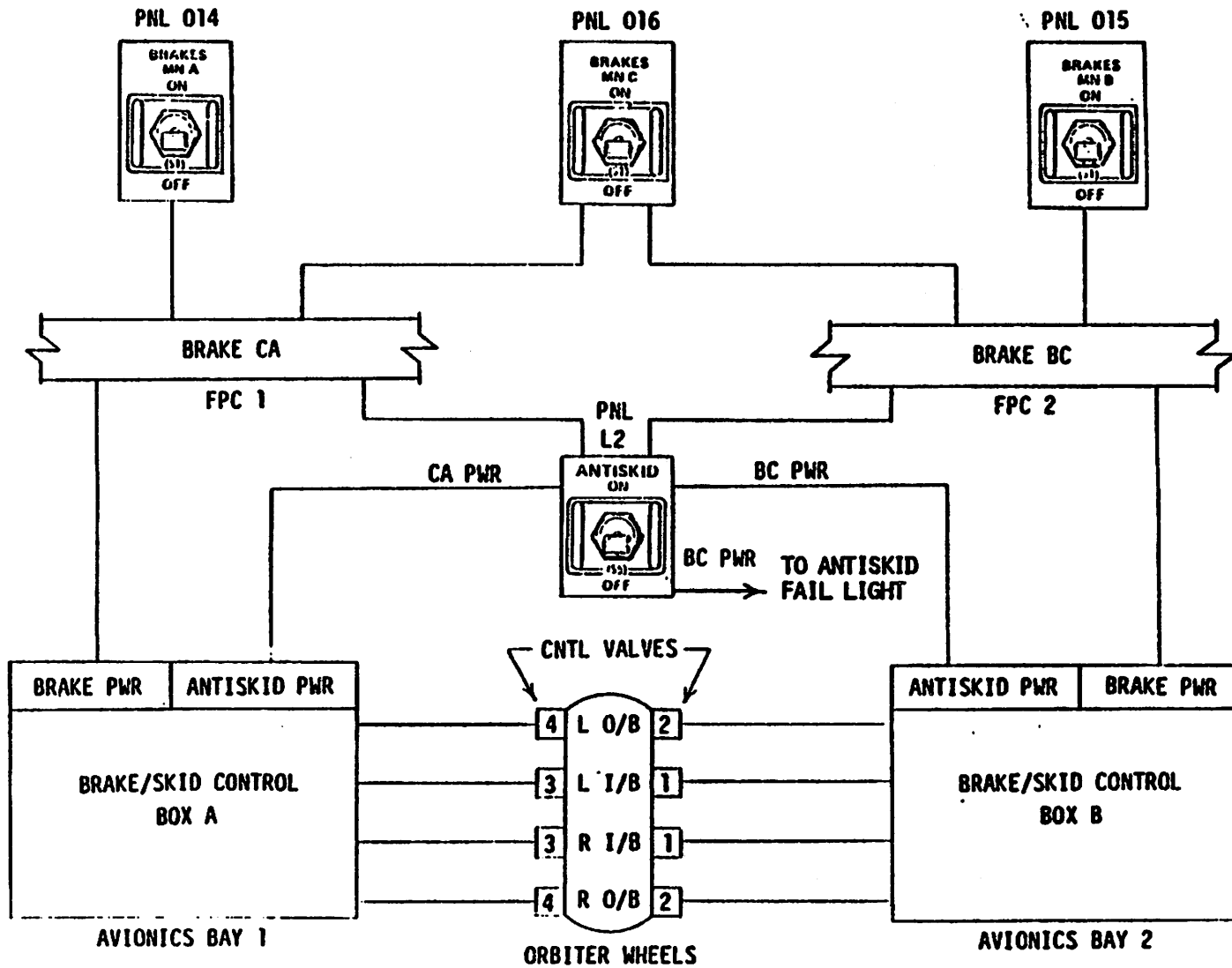


Figure 3-14.- Brake/skid control power.

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3.2.4 Brake/Skid Control Overview

Figure 3-15 depicts a simplified overview of the Brake/Skid Control System which includes the brake/skid controls and major components. The major components of the brake/skid control system are as follow:

- Rudder Pedal Assemblies - The CDR and PLT both have rudder pedal assemblies. Braking is initiated by toe pressure on the pedals.
- Brake Pedal Transducers - Each pedal assembly has eight transducers. When toe pressure is applied, the transducers output braking signals (0-5 VDC) to the brake/skid control boxes.
- Brake/Skid Control Boxes - Braking signals are input to Brake/Skid Control Boxes A and B. Each box contains four brake/skid control circuits. Each circuit controls the braking performance of one of the eight brake chambers. Each circuit also provides skid control protection and controls illumination of the ANTISKID FAIL light. When the braking signals from the CDR's and/or PLT's brake transducers are input into the brake/skid control boxes, they are connected through an OR circuit which allows control from the pedals which command the greatest pressure.
- Hydraulic Switching Valves - Four hydraulic switching valves supply hydraulic pressure to the eight brake/skid control valves. Two hydraulic systems supply each switching valve. If the active hydraulic system pressure decreases below a certain range, the switching valve will switch to the standby system.
- Brake/Skid Control Valves - The brake system contains eight modulating brake/skid control valves which receive signals from the brake/skid control boxes. Each valve controls the hydraulic brake pressure to one of the eight brake chambers. The brake/skid control valves contain a brake coil and a skid coil. The brake coil allows hydraulic pressure to the brake chambers. The skid coil, when energized by the skid control circuit, provides reverse polarity to the brake coil, thus preventing the brake coils from allowing brake pressure to the brake chamber.
- Brake Chambers - Each of the four main wheels have two hydraulic brake chambers. Each brake chamber supplies the hydraulic pressure to four brake actuators.
- Wheel Speed Sensors - Each main wheel has two-wheel speed sensors. The sensors provide wheel velocity information to the skid control circuits in the brake/skid control boxes.

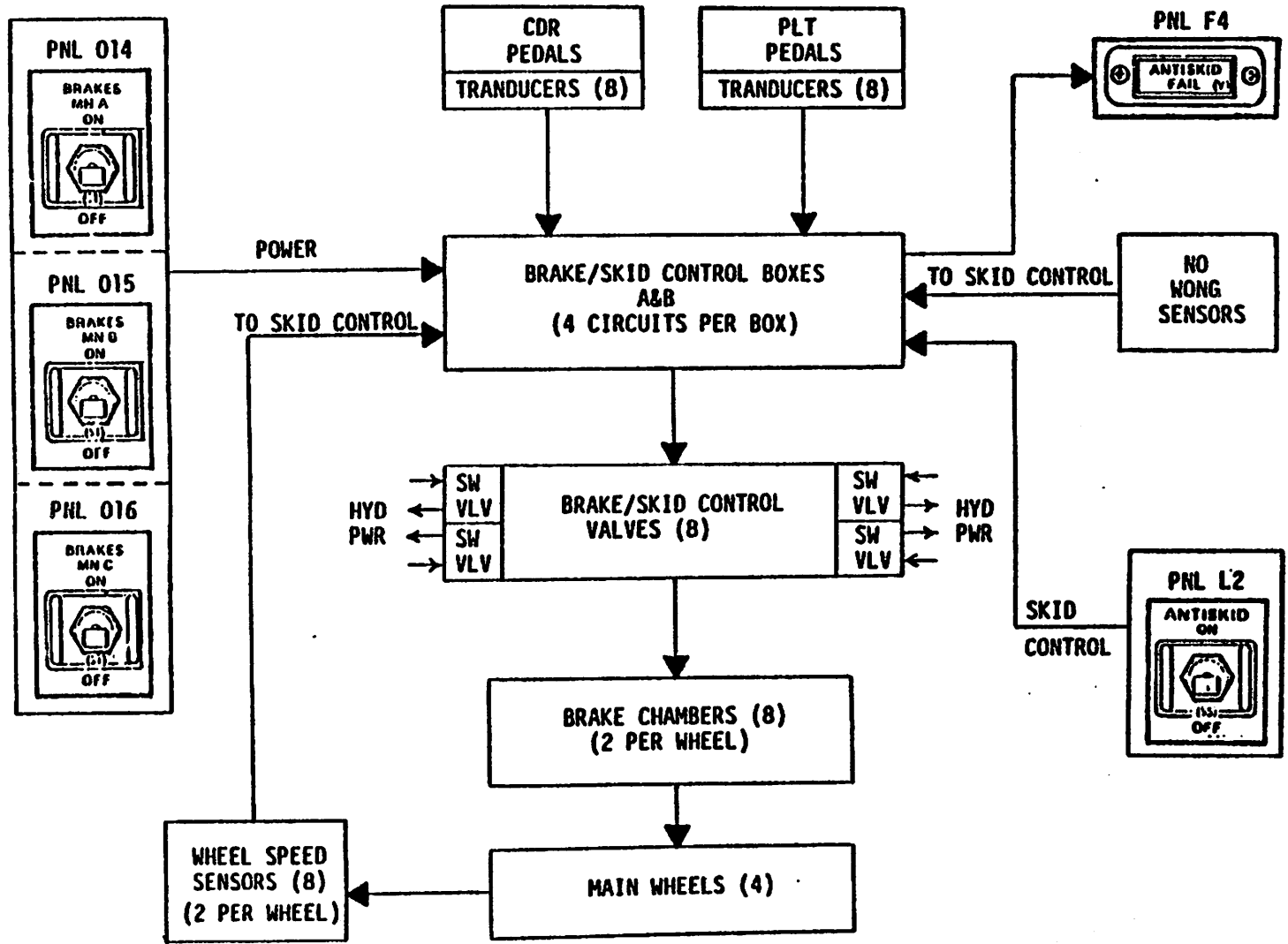


Figure 3-15.- Brake/skid control system overview.

3.2.5 Wheel Brake Subsystem

Figure 3-16 depicts the Wheel Brake subsystem and its interface with the hydraulic systems, the brake/skid control valves, and the brake/skid control boxes. All three hydraulic systems supply hydraulic pressure to the brakes through four switching valves. Systems 1 and 2 are the active systems and System 3 is the standby system. Each switching valve supplies hydraulic pressure to two brake/skid control valves, and each brake/skid control valve controls hydraulic pressure to a brake chamber. Hydraulic System 1 supplies Brake/Skid Control Valves 1 and 2 which control pressure to Brake Chambers 1 and 2. Hydraulic System 2 supplies Brake/Skid Control Valves 3 and 4 which control pressure to Brake Chambers 3 and 4. Brake/Skid Control Box A controls Brake/Skid Control Valves 3 and 4 and Brake/Skid Control Box B controls Brake/Skid Control Valves 1 and 2. As can be concluded from studying the wheel brake drawing, the brake system contains much redundancy. As long as one brake chamber on each wheel is providing braking hydraulic pressure, the Orbiter crew can perform a normal energy stop. However, the braking distance will be approximately 30-40 percent longer.

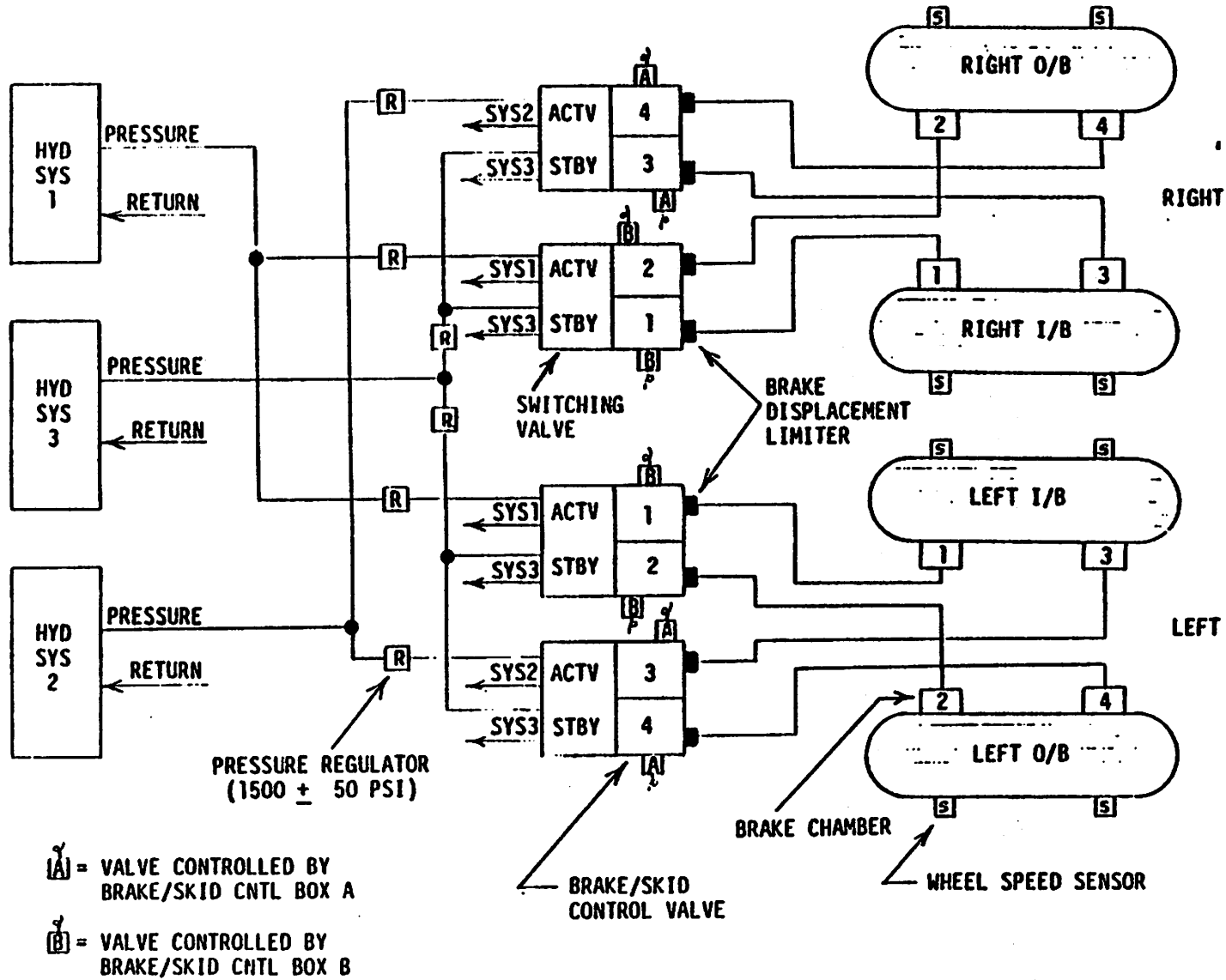


Figure 3-16.- Wheel brake subsystem.

3.2.6 Skid Control

As indicated in earlier sections, each of the eight circuits in the two brake/skid control boxes contain skid control circuits as well as braking circuits. Each circuit inputs wheel speed sensor data and then modulates its associated brake/skid control valve as required to provide antiskid control protection. To activate antiskid the BRAKE POWER switches and the ANTISKID switch must be turned ON. The antiskid circuits will control brake pressure as required to provide optimum braking without tire skidding, wheel locking, or tire damage. Skid control is disabled between 10 to 15 knots to prevent loss of manual braking during parking and maneuvering.

The types of skid control protection provided are defined as follow:

- Skid and Lock Wheel - The wheel velocity of each wheel is continuously compared to the average wheel velocity of all four wheels. Whenever the wheel velocity of a wheel is below 30 percent of the average velocity of the four wheels, skid control removes brake pressure until the velocity of that wheel increases to an acceptable range.
- Flat Tire Protection - The wheel velocity of each wheel is continuously compared to the average wheel velocity of all four wheels. Whenever the wheel velocity of a wheel is below 30 percent of the average velocity of the four wheels for 2 sec, the tire on that wheel is considered flat and the brake pressure on the adjacent wheel is limited to 800 ± 100 psi to prevent brake or tire damage to that wheel.
- Touchdown Protection - Whenever the ANTISKID switch is ON, touchdown protection prevents brake application until at least one of the NO WONG 1 or NO WONG 2 signals is lost (refer to Figure 3-7).

3.2.7 Antiskid Fail Light

The antiskid circuits have fault detection circuits which will detect certain brake system failures and illuminate the ANTISKID FAIL light. It should be emphasized that a detected failure will only deactivate the failed circuit and not total antiskid control. The brake system failures and an ANTISKID FAIL light status chart are shown in Figure 3-17.

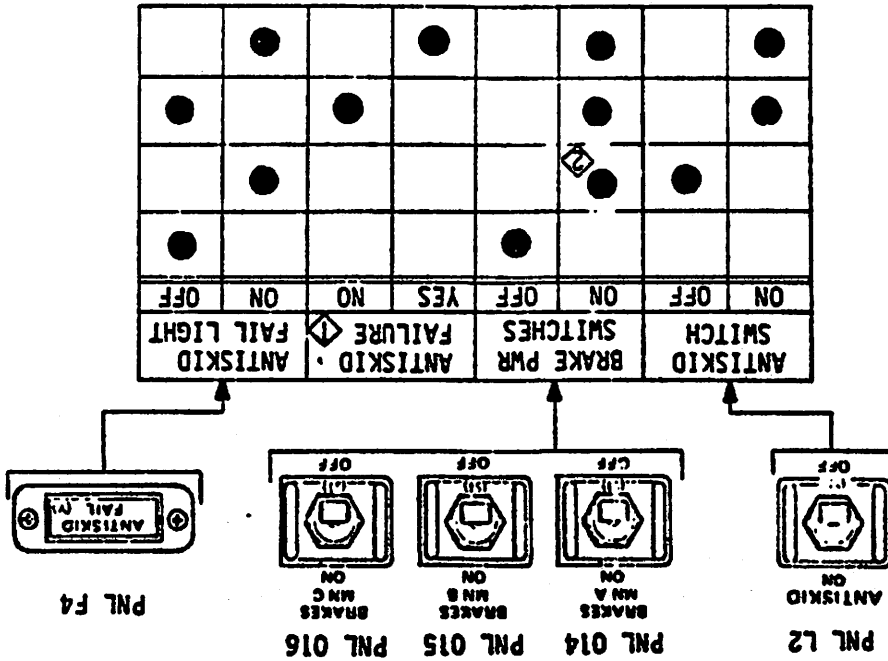
Figure 3-17.- Antiskid fail light status.

NOTE: A FAILURE WILL ONLY DEACTIVATE THE FAILED CIRCUIT AND NOT TOTAL ANTISKID CONTROL.

- OPEN OR SHORT IN A WHEEL SPEED SENSOR CIRCUIT.
- OPEN OR SHORT IN A SKID CONTROL SERVO VALVE CIRCUIT.
- FAILURE IN A ANTISKID CONTROL CIRCUIT.

ANY OF THE FOLLOWING FAILURES: 1

ANTISKID FAULT DETECTION CIRCUITS DETECTS 2 APPLIES ONLY TO BRAKE POWER SWITCHES MN B, MN C, OR BOTH TO BE ACTIVATED.



3.3 NOSE WHEEL STEERING SUBSYSTEM

3.3.1 Nose Wheel Steering Power

Main Bus A provides power for the NWS system (Figure 3-18). When the nose wheel steering circuit breaker is CLOSED, Main Bus A power is distributed to the DIRECT and GPC positions of the NWS switch. When the NWS switch is placed in either of these positions, Main Bus A power will power up the nose wheel steering control box. If the circuit breaker is OPEN or if Main Bus A is lost, the nose wheel steering system cannot be activated. Also, when the NWS switch is placed in either the DIRECT or GPC position, a control bus will provide power to a circuit driver which will allow annunciator circuit lamp power to illuminate the NWS FAIL light until the NWS system is enabled. The NWS FAIL light cannot be illuminated when the NWS switch is in the OFF position.

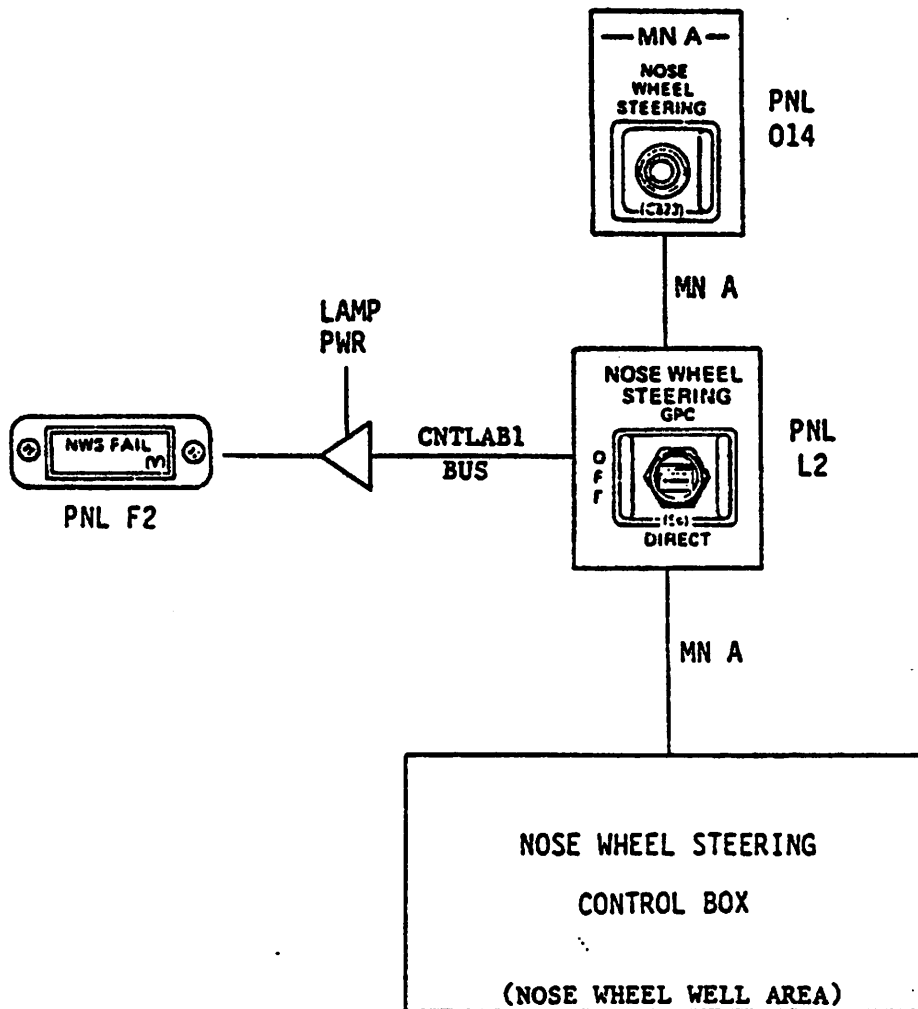


Figure 3-18.- Nose wheel steering power.

3.3.2 Nose Wheel Components

Refer to Figure 3-19 for the NWS system discussions in this section. Nose wheel steering is performed by a steering actuator assembly located on the NLG strut. The actuator is electrically controlled and powered by Hydraulic System 1. When NWS is not activated, the steering actuator provides the damping force required to prevent wheel shimmy and allow the nose wheels to free castor through $\pm 10^\circ$ of rotation. The NWS system consists of three major functional components:

- Rudder Pedal Assembly - The flight crew performs NWS by using the rudder pedals. The rudder pedal assembly contains a Rudder Pedal Transducer Assembly (RPTA) and a NWS command transducer. The transducer utilized depends on the position of the NWS switch. When in the DIRECT position, steering signals are initiated by the NWS command transducer. The amount of angular NWS will be proportional to the degree of rudder pedal deflection. When in the GPC position, steering signals are initiated by the RPTA and sent to the GPC's which, in turn, output computer steering signals. The amount of angular NWS will be proportional to the value of the computer steering signal.
- Steering Control Box - The steering control box receives all steering signals and outputs them to the steering actuator assembly. The steering control box receives position feedback signals from the feedback transducer which is located within the steering actuator assembly. The feedback transducer signals are used by the steering control box for nose wheel position verification. The steering control box also has failure detection logic that will disable NWS and illuminate the NWS FAIL light. The failure detection logic is discussed in paragraph 3.3.4.
- Steering Actuator Assembly - When the NWS switch is activated, the steering control box will output signals (28 VDC) to open the solenoid pilot valve which ports Hydraulic System 1 pressure to the servo control valve. NWS is enabled when the hydraulic pressure switch (SW) detects that the hydraulic pressure is at least 1350 psig. If NWS is enabled and the pressure switch detects that the hydraulic pressure falls to 1000 ± 150 psig, then the steering control box will disable NWS. When NWS is enabled, steering signals (± 5 VDC) from the steering control box to the servo control valve will allow hydraulic pressure to the steering actuator for nose wheel steering. The position feedback signals from the steering actuator are sent back to the steering control box for position verification and failure detection. When NWS is disabled or the NWS switch is OFF, the pilot valve is closed and lack of hydraulic pressure to the two pressure actuated valves near the steering actuator will allow hydraulic fluid in either direction for free castoring of the wheels.

3.3.3 Nose Wheel Operations

NWS operations will be described with respect to the positions of the NWS switch. The NWS switch has three operational positions: OFF, DIRECT, and GPC.

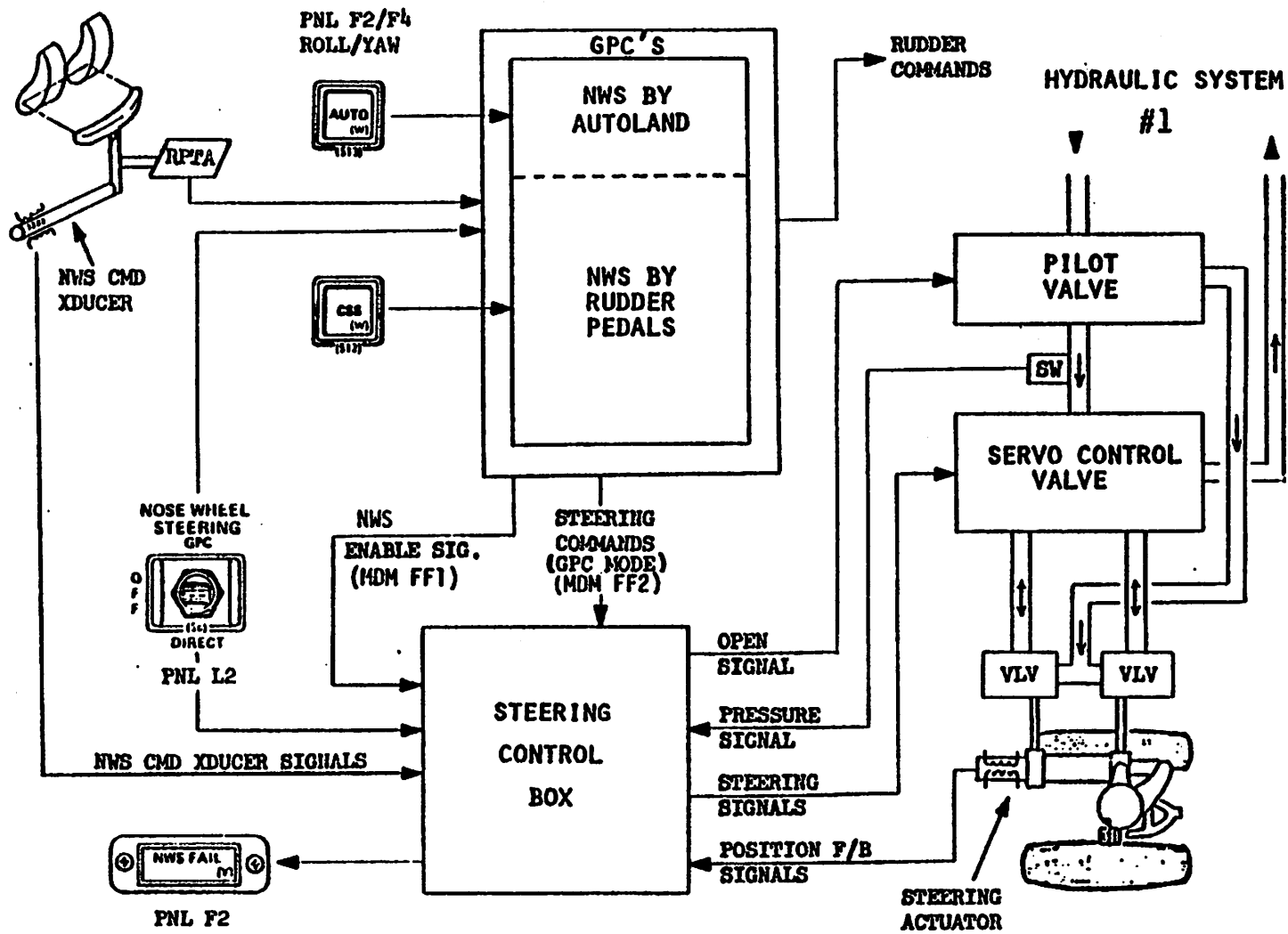


Figure 3-19.- Nose wheel steering.

- o OFF - When the NWS switch is OFF, NWS is disabled and steering can be accomplished by rudder steering using the rudder pedals and differential braking using the main wheel brakes.
- o DIRECT - When the NWS switch is in DIRECT, steering is accomplished using the rudder pedals. In the DIRECT mode, steering signals are sent from the NWS command transducer direct to the steering control box and then to the steering actuator. In the DIRECT mode, NWS is disabled until the NWS ENABLE signal is received from the GPC. If the Backup Flight system is ENGAGED, nose wheel steering is available only in the NWS DIRECT mode.
- o GPC - When the NWS switch is in GPC, steering can be accomplished using the rudder pedals or by the AUTOLAND system. The methods used depends on the positions of the flight control mode ROLL/YAW PBI's on Panels F2 or F4. If it is desired to steer by the AUTOLAND System while in the NWS GPC mode, then the FC mode ROLL/YAW AUTO PBI must be activated. In this mode all rudder pedal inputs from the RPTA are inhibited and steering signals are generated by the GN&C system and sent to the steering control box. Steering by AUTOLAND is automatic and does not require crew manual steering inputs. If it is desired to steer using the rudder pedals while in the NWS GPC mode, then the FC mode ROLL/YAW PBI's must be in the CSS mode. In the CSS mode, steering signals are initiated by the RPTA, sent to the GPC for parabolic shaping, and then routed to the steering control box. When in GPC mode, NWS disabled until the NWS ENABLE signal is received.

3.3.4 Nose Wheel Steering Fail Light And System Failures

As discussed earlier, the nose wheel steering control box contains failure detection logic which will illuminate the NWS FAIL light and disable NWS. Table 3-1 defines these system failures and the NWS FAIL light status with respect to these failures, the NWS switch position and the NWS ENABLE signal. The available methods of steering for each condition are also shown.

It was learned in the NWS power section that, when the NWS switch is placed in the DIRECT or GPC position, a control bus will provide power to a circuit driver which will allow annunciator circuit lamp power to illuminate the NWS FAIL light. However, as soon as the NWS system is enabled by the steering control box, a ground will be provided which will extinguish the NWS FAIL light. A simplified logic drawing, which depicts the conditions which will cause the NWS FAIL light to be extinguished, is shown in Figure 3-20.

In paragraph 3.3.2, it was learned that when the NWS switch is activated, i.e., placed in the DIRECT or GPC position, the steering control box will output a signal to open the pilot valve to allow hydraulic pressure to the servo control valve. However, the pilot valve cannot open until the pilot valve circuit is completed (i.e., grounded) as shown by the two connected AND gates in figure 3-21. When the conditions of the two AND gates are

satisfied, the pilot valve will be grounded and will allow hydraulic pressure to the servo control valve and pressure switch. Once the pressure switch is activated, it will cause the NWS FAIL light to extinguish.

The NWS FAIL light will also be extinguished when the conditions of the single AND gate are satisfied. The circuit in Figure 3-20 should be studied with the NWS FAIL light status chart in Table 3-1 to obtain a better understanding of the NWS FAIL light circuits.

TABLE 3-1.- NOSE WHEEL STEERING FAIL LIGHT STATUS AND AVAILABLE METHODS OF STEERING

NWS SWITCH POSITION			FAILURE LOGIC DETECTS FAIL ▲		NWS FAIL LIGHT STATUS		AVAILABLE METHODS OF STEERING ▼
OFF	DIR	GPC	NO	YES	NO NWS ENBL SIGNAL	NWS ENBL SIGNAL	
X			N/A	N/A	OFF	OFF	DIFFERENTIAL BRAKING (NOSE WHEELS CASTOR)
	X		X		ON	OFF	NWS BY RUDDER PEDALS (CMD XDUCE)
	X			X	ON	ON	DIFFERENTIAL BRAKING (NOSE WHEELS CASTOR)
		X	X		OFF	OFF	NWS BY RUDDER PEDALS (RPTA) OR AUTOLAND
		X		X	OFF	ON	DIFFERENTIAL BRAKING (NOSE WHEELS CASTOR)

▲ **FAILURE LOGIC**

The Steering Control Box has detected one or more of the following failures:

- Low hydraulic pressure
- Open or short in servo control valve
- Open or short in the NWS CMD transducer
- Open or short in the position transducers
- Loss of steering control box power
- Broken linkage(command transducer)
- Hard-over condition

▼ **Applies only after the "NWS Enable" signal is received.**

Before the "NWS Enable" signal is received the available methods of Orbiter steering are:

- Differential Braking
- Rudder Steering

PROVIDES A GROUND WHICH WILL EXTINGUISH THE NWS FAIL LIGHT

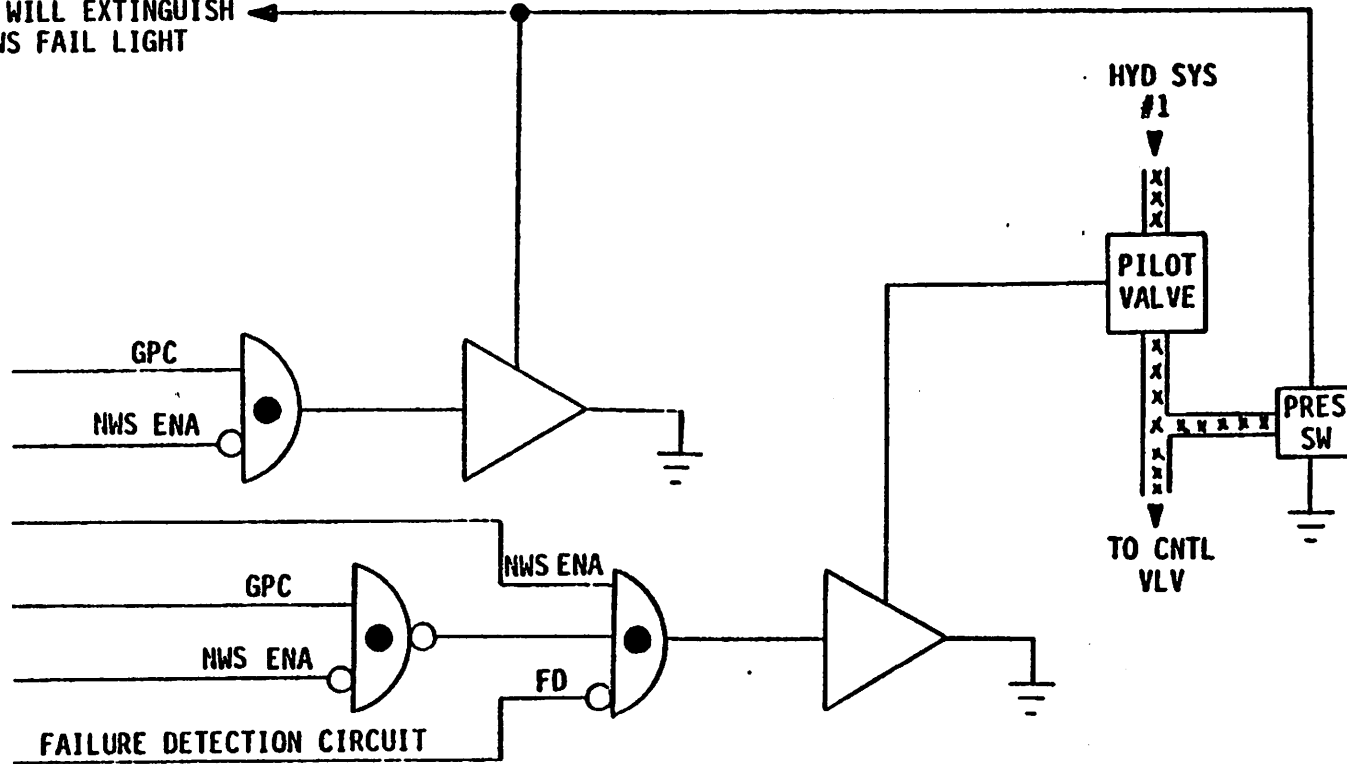


Figure 3-20.- Nose wheel steering fail light logic (simplified).

SECTION 4
DISPLAYS AND CONTROLS (D&C)

The Landing/Deceleration system controls and displays are described in Table 4-1.

TABLE 4-1.- LANDING/DECELERATION SYSTEM CONTROLS AND DISPLAYS

PANEL	TYPE	NOMENCLATURE POSITION	FUNCTION	REMARKS	
F6&F8	FLAG	LEFT, NOSE, RIGHT			
			UP	INDICATES LANDING GEAR IS UP.	
			BP	INDICATES LANDING GEAR IS IN TRANSIENT OR POWER TO FLAGS IS ABSENT.	BARBERPOLE.
			DN	INDICATES LANDING GEAR IS DOWN.	
F6&F8	PBI	ARM			
			ILLUMINATED (PRESSED)	ARMS LANDING GEAR CIRCUITS.	
		DN			
			ILLUMINATED (PRESSED)	DEPLOYS LANDING GEAR.	ARM PBI MUST FIRST BE ACTIVATED.
L4	CB	LG SNSR 1 OPEN, CLOSE	PROVIDES AC300A POWER TO LANDING GEAR PROXIMITY SENSOR PACKAGE #1 WHEN CLOSED.	THESE SENSORS OUTPUT SIGNALS WHICH DRIVE THE LANDING GEAR POSITION TALKBACK FLAGS.	
		LG SNSR 2 OPEN, CLOSE	PROVIDES AC200A POWER TO LANDING GEAR PROXIMITY SENSOR PACKAGE #2 WHEN CLOSED.		
R4	SW	LG RETRACT/CIRC VLV		THIS VALVE MUST BE OPEN FOR HYDRAULIC FLUID THERMAL CONDITIONING AND FOR GEAR RETRACTION.	
			OPEN		OPENS THE LANDING GEAR RETRACT/CIRCULATION VALVE.
			GPC		ALLOWS THE GPC TO OPEN OR CLOSE THE VALVE.
			CLOSE	CLOSES THE VALVE.	
R15	CB	LDG GEAR ARM/DN RESET	PROVIDES ES18C POWER TO THE LG ARM/DN RESET SWITCH.		

TABLE 4-1.- LANDING/DECELERATION SYSTEM CONTROLS AND DISPLAYS - Concluded

PANEL	TYPE	NOMENCLATURE POSITION	FUNCTION	REMARKS
A12	SW	LG ARM/DN RESET RESET	DE-ENERGIZES THE LANDING GEAR ARM AND DN PBI CIRCUITS.	EXTINGUISHES THE ARM & DO PBI LIGHTS AND RETURNS THE LANDING GEAR HYDRAULIC VALVES TO THEIR NORMAL UNPOWERED STATE.
014	SW	BRAKES MN A ON, OFF	PROVIDES MAIN BUS A POWER TO THE BRAKE/SKID CONTROL CIRCUITS.	
015	SW	BRAKES MN B ON, OFF	PROVIDES MAIN BUS B POWER TO THE BRAKE/SKID CONTROL CIRCUITS.	
015	SW	BRAKES MN C ON, OFF	PROVIDES MAIN BUS C POWER TO THE BRAKE/SKID CONTROL CIRCUITS.	
L2	SW	ANTISKID ON, OFF	ACTIVATES THE BRAKES ANTISKID CIRCUITS.	BRAKES MN A, MN B, AND MN C POWER SWITCHES MUST BE ON.
L2	SW	NOSE WHEEL STEERING DIRECT GPC OFF	ALLOWS MANUAL DIRECT NWS USING RUDDER PEDALS AND NWS COMMAND TRANSDUCER. ALLOWS MANUAL NWS USING RUDDER PEDALS THRU RPTA, OR ALLOWS AUTOLAND NWS. DISABLES NWS.	POWERS UP THE NOSE WHEEL STEERING CONTROL BOX WHEN IN GPC OR DIRECT MODE. DEPENDS ON POSITION OF FC MODE ROLL/YAW PBI'S.
F2	INDI-CATOR	NWS FAIL	INDICATES THAT NWS IS DISABLED WHEN ILLUMINATED.	
F4	INDI-CATOR	ANTISKID FAIL	INDICATES AT LEAST ONE OF THE 8 BRAKE/ANTISKID CIRCUITS HAS FAILED.	
014	CB	NOSE WHEEL STEERING OPEN, CLOSE	PROVIDES MAIN BUS A POWER TO THE NOSE WHEEL STEERING SWITCH.	

SECTION 5
SYSTEMS PERFORMANCE, LIMITATIONS, AND CAPABILITIES

The Landing/Deceleration System performance, limitations, and capabilities are defined in the following paragraphs.

5.1 LANDING GEARS

Landing Weight	188,000 lb - Normal 227,000 lb - Maximum
NLG Derotation Rate	9.4 ⁰ sec - Maximum
MLG Allowable Sink Rate	9.6 fps - Normal weight, no crosswind
	6.0 fps - Normal weight, 20 knot crosswind
	6.0 fps - Maximum weight, no crosswind
	5.0 fps - Maximum weight, 20 knot crosswind
Gear Deployment Velocity	300 knots - Maximum
Gear Extension Time	6-8 sec - Normal
	10 sec - Maximum
Landing Velocity	225 knots - Maximum
Crosswind	20 knots - Maximum
Runway Constraint	10,000 ft - Wet & Grooved
Gear Extension Method	Freefall - After gear uplock hook release
Gear Uplock Hook Release	Hydraulic System #1 - Primary Dual PYRO's - Backup
Gear Retraction	Ground Only
Tire Load (max per tire)	Nose Landing Gear - 45,000 lb
	Main Landing Gear - 100,000 lb
Tire Life	5 normal landings

Wheel Assembly Temperature (Tires, wheels, brakes)	-65° F	- Min Operating Temp
	250° F	- Max Operating Temp (long term)
	275° F	- Max Operating Temp (5 minutes)

5.2 BRAKES

The Orbiter brakes are designed for five normal energy stop landings or one emergency stop landing. The criteria for a normal energy stop landing and an emergency stop landing are provided in Figure 5-1. A normal energy stop landing is defined as a landing in which a 188,000 lb Orbiter begins initial braking at 153 knots and the braking Kinetic Energy (KE) of the four brakes does not exceed 146×10^6 ft-lb. Under these conditions a normal energy stop can be performed in 2860 ft using 1500 psi braking pressure. An emergency stop landing is defined as a landing in which a 227,000 lb Orbiter begins initial braking at 178 knots and uses up to 222×10^6 ft-lb of braking KE. Under these conditions an emergency stop landing could be performed in 4364 feet using 1500 psi braking pressure.

Preliminary engineering data indicates that when the braking KE of an Orbiter landing exceeds 146×10^6 ft-lb, brake reuse is questionable, i.e., the brakes may have to be refurbished prior to the next flight. The total braking energy chart in Figure 5-1 depicts the total braking energy required to stop an Orbiter with respect to various Orbiter weights and initial braking velocities. The data also indicates that during the total braking period, if the Orbiter decelerates at 8 ft/s^2 or less, then the probability of exceeding 146×10^6 ft-lb of braking KE is small and the chances of brake reuse is high. Also indicated on the braking energy chart is the braking KE (234×10^6 ft-lb) which will cause total brake failure.

The braking stopping distance for various Orbiter weights utilizing 1500 psi braking pressure, and the braking stopping distance for 8 ft/s^2 deceleration is provided in Figure 5-2. This figure, along with Figure 5-1, can be correlated to figure the total braking energy and braking stopping distance. It should be emphasized, however, that this data is only preliminary and that future testing could alter this brake performance data.

5.3 NOSE WHEEL STEERING

Nose Wheel Steering Hydraulics	System #1
Steering Angle (Maximum)	$\pm 10^\circ$

TABLE 5-I.- BRAKE DYNAMIC LOADING CONDITIONS

Condition	Touch Down Velocity (FPS)	Initial Braking Vel. (FPS)	Braked Stopping Distance (FT)	Per Brake KE (10 ⁶ Ft-Lbs)	Number of Stops
I Orbit Mission 32K P/L Normal Landing (Sea Level-Hot Day) 188 K ORBITER	337.8 (200 Knt)	258.4 (153 Knt)	2860	36.5	5
II Orbit Mission 65K P/L Emerg. (Sea Level-Hot Day) 227 K ORBITER	373.3 (221 Knt)	300.7 (178 Knt)	4364	55.5	1

THE WHEEL/BRAKE SYSTEM SHALL OVERCOME THE KINETIC ENERGY OF ORBITER LANDING AND CONTROL THE ORBITER TO A SAFE STOP, AND SHALL BE CAPABLE OF MEETING THE ENERGY CONDITIONS IN THE ABOVE TABLE. (SD 72-SH-0102-1)

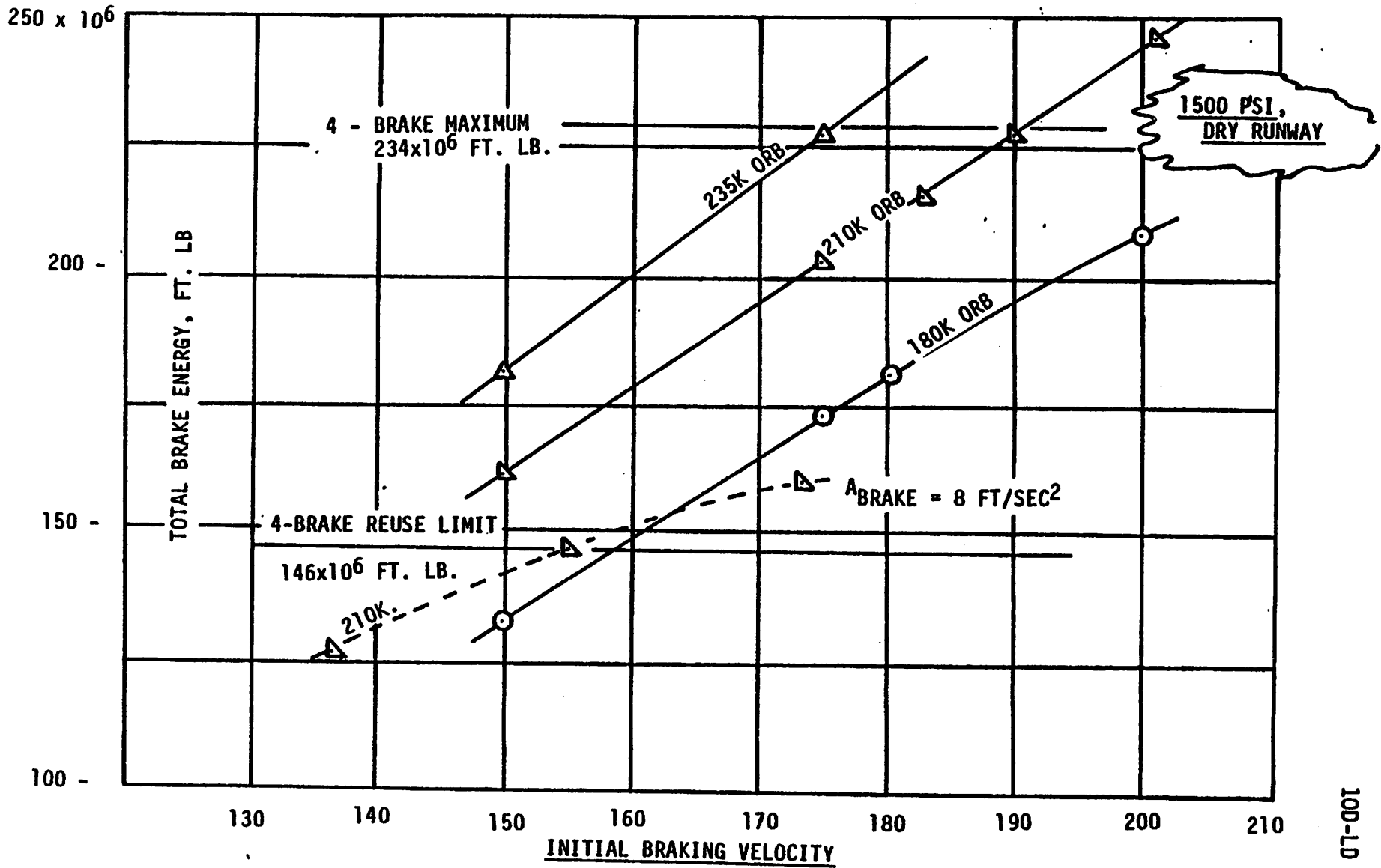


Figure 5-1.- Total braking energy.

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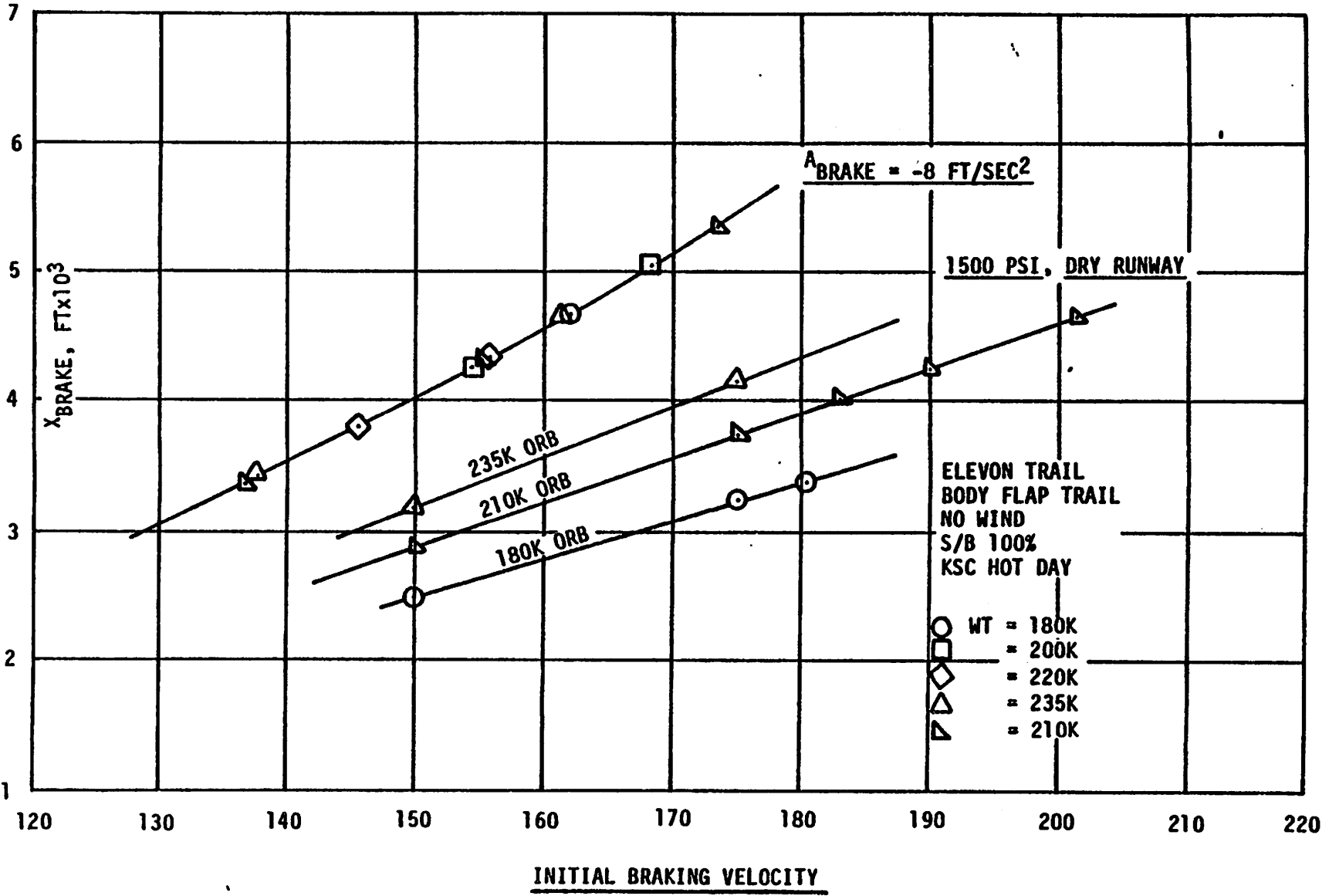


Figure 5-2.- Brake stopping distance.

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